Color Atlas of Dental Medicine

Editors:
K. H. Rateitschak
H. F. Wolf

TMJ Disorders and Orofacial Pain

The Role of Dentistry in a Multidisciplinary Diagnostic Approach

Axel Bumann, Ulrich Lotzmann

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In Collaboration with James Mah

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To my sons Philipp and Sebastian,
as well as to my parents,
in gratitude for their love, patience,
support and their understanding

To my teachers,
Rolf Ewers, Louis C. Gerstenfeld,
Asbjorn Hasund, Marcel Korn,
Robert M. Ricketts and Edwin H. K. Yen,
who influenced my development significantly

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with great love and gratitude

To *the crew of Apollo Xll:*
Charles "Pete" Conrad (1930-1999), in memory;
Richard Gordon and Alan Bean,
in admiration and friendship

Ulrich Lotzmann

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Foreword

The title of this opus presents the philosophy of the authors, namely that dentistry is only one part of a multi-faceted service for temporomandibular dysfunction. Dentists would argue that their service is the most important. Indeed, TMJ problems are largely within the province of dental care; however, like a horse with blinders, therapy has concentrated on the mechanical aspects, largely ignoring the physiological and psychological areas that are so important, if we are to render optimal service. In other words, dentistry itself must broaden its diagnostic and therapeutic horizons and de-emphasize the tooth-oriented vision and mechanical procedures. The authors clearly state this in their preface - based on their great clinical experience. If the reader is looking for a fancy articulator that replicates the stomatognathic system, he is in the wrong place.

Too many dentists have been led down the primrose path, aided by TOT (tincture of time) as patients improve, regardless of the therapy employed. TMJ problems are largely cyclic, and are often self-correcting via homeostasis, with time and advancing age.

The pseudo-science of Gnathology has been built around the mechanical contrivances of articulators and facebows, but provide only part of the answer, at best. Lysle Johnston, a highly respected professor of orthodontics at the University of Michigan, has facetiously defined Gnathology as "The science of how articulators chew!" They are only a tool in the panoply of diagnostic aids; sometimes more important, if the teeth are a major factor in the TMJ complaint. Too often, however, they are only a part, as the authors wisely say, based on their great clinical experiences. Thus this book is dedicated to making dentists into applied biologists, applied physiologists, applied psychologists, as well as good mechanics who can restore, reshape, reposition and beautify teeth and get that smile winning smile. Mounting of casts is carefully and completely covered by Drs. Bumann and Lotzmann, as only one part of the diagnostic mosaic.

The beautifully illustrated section on the anatomy and physiology of the stomatognathic system provides a comprehensive discourse on all essential components of the stomatognathic system. Skeletal, structural, and neuromuscular aspects are well illustrated, providing an excellent understanding of each part and the interrelationships, without verbosity. We must remember that the teeth are in contact roughly 60-90 minutes per 24 hours. The dominant structures are the neuromuscular structures, which suspend the mandible and provide its vital function in mastication, deglutition, breathing and speech. Dentistry must get over its pre-occupation with the idea that it is "the teeth, the whole teeth, nothing but the teeth!" This book is a breath of fresh air, as it analyzes the basic structures involved and the roles that the skeletal osseous parts, the condyle, the glenoid fossa, the articular disk, the capsule, ligaments, muscles and that too-often neglected retrodiskal pad (bilaminar zone) play in the whole picture. Equally important, as we assemble the diagnostic mosaic for treatment, is the psychological role, the stress-strain-tension release mechanisms that we resort to in our complex society today. We must make sure, in our diagnostic exercise, that we know which is *cause* and which is *effect*. Wear facets on teeth may well be the result of nocturnal parafunctional activity, i.e., bruxism. And even more important, and too often neglected, is nocturnal clenching, which is also a manifestation of the stress-strain release syndrome, especially at night. Lars Christensen showed conclusively that as little as 90 seconds of clenching can cause neuromuscular response, i.e., pain and muscle splinting. Does the condyle impinge on the retrodiskal pad, with it's network of nerves and blood vessels, and the important role it plays in the physiology of the temporomandibular joint? Here again, important information is provided by the authors, based on the landmark work of Rees, Zenker and DuBrul. Recent research validates the important role that the bilaminar zone or retrodiskal pad plays in TMJ physiology. Thilander showed in 1961 that pain response in the temporomandibu-

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lar joint can come from condylar impingement on this neglected post-articular structure. Isberg showed graphically the damage possible by forced impingement on the same tissues. Yet we have to be smart enough to know the difference between cause and effect.

Functional analysis is a key to most TMD diagnostic exercises. Only then can articulator-oriented rebuilding of teeth be biologically based and physiologically sound. Drs Bumann and Lotzmann have stressed this orientation in their fine book. Their sections on functional analysis is state of the art. The role of physical therapy is clearly defined, Orthodontist perhaps have been exposed to this more in their training and the knowledge should benefit general dentists. As well.

We realize that we are clearly in the new millennium, when we read the section on Imaging Procedures. What are the best diagnostic tools available? For what structures? Because of the difficulty of getting precise images of the complex temporomandibular joint, more than one radiographic assessment may be needed. Knowing what each imaging tool can produce is important. Yet, the material presented is lucid and understandable and not needlessly technical. Criteria are tied to the various potential abnormalities.

Diagnosis is the name of the game and its imperfect application by countless clinicians has made it the Achilles heel of TMJ therapy. Tying together the anatomic, physiologic, and psychological elements is essential for optimal patient service. As in all other sections, a comprehensive bibliography permits the reader to explore these tools further.

The multifaceted nature of cause-oriented TMD therapy is covered well, as the various types of appliances are described and the indications for their use given. The aphorism that "a splint is a splint is a splint" is ludicrous, in light of the biologic background elucidated by the authors. Depending on the diagnostic assessment and classification described beforehand, the clinician may use a relaxation splint, a stabilization splint, a decompression splint, a repositioning splint, or a verticalization splint. Again, diagnosis is the name of the game in their choice. Along with supplemental use of muscle relaxants, heat, infrared radiation, stress relief and counseling.

Profuse color illustrations make following the text easy and enhance the understanding of the concepts. A recent scientific study showed conclusively that color pictures are easier to comprehend by the human brain. This color atlas is a good example of this fact. Excellent production, for which Thieme is noted, enhances the value of the book. Read, enjoy and learn!

T.M. Graber, DMD, MSD, PhD, MD, DSc, ScD, OdontDr. FRCS.
Professor

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Foreword

The authors of this extraordinary atlas have given the dental profession an extremely comprehensive and well-organized treatise on the functional diagnosis and management of the masticatory system. Historically, dental literature in the field of occlusion has been primarily based on clinical observations, case reports and testimonials. This extremely well referenced atlas is a welcome addition to the momentum within the dental profession to move the field forward to a more evidenced-based discipline. The multidisciplinary diagnostic approach presented in the atlas is well established and supported by published data. Chapters include up-to-date information and exquisite photography on the anatomy, physiology, pathology and biomechanics of masticatory system, as well as detailed diagnostic techniques. The theme of the atlas is based on the importance of the coordinated functional interaction between the tissue populations of the various stomatognathic structures. The authors emphasize the need for thorough functional analyses in order to accurately determine if the dynamic physiologic relationship between the various tissue systems is functional or dysfunctional. As so beautifully illustrated in the text, when there is a disturbance in this dynamic functional equilibrium due to injury, disease, adverse functional demands or a loss in the adaptive capacity of the tissues, tissue failure and functional disturbances can occur. The authors present precise and very comprehensive clinical functional analysis techniques for establishing specific diagnoses, and ultimately, improved treatment planning. Multidisciplinary treatment planning based on the data derived from diagnostic functional analyses including established orthopedic techniques, intraoral examinations, imaging and instrumented testing systems is expertly explained in easy to follow steps. The emphasis throughout the atlas is that diagnostic-driven treatment is based on the specific needs of the individual patient rather than based on a preconceived belief system or on a stereotyped concept thought to universally ideal. Treatment plans are based on cause-oriented functional disturbances that may need to be modified by the patient's compliance, general health and emotional status in addition to the clinician's abilities, training and experience.

I congratulate Drs. Alex Bumann and Ulrich Lotzmann for their outstanding efforts in providing the profession with an extremely well organized, skillfully written, and beautifully illustrated atlas. I especially appreciated their attempt to provide the reader with, wherever possible, current and complete references and, thus, add important evidenced-based literature to the field. This treatise on functional disturbances of the stomatognathic system should be required reading for anyone interested in the diagnostic process and treatment planning in dentistry in general. Additionally, the detailed chapters describing the various diagnostic functional techniques with accompanying exquisite illustrations make this an outstanding comprehensive teaching atlas in occlusion for students and clinicians,

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Foreword

Dr Bumann and Dr Lotzmann are two authors with an outstanding amount of information and illustrations at their disposal. Working together with Thieme, a publisher known for its ability to communicate through the use of illustrations, to produce this book has proven to be a perfect collaboration.

Imaging can play an important role in the diagnostic and treatment processes associated with orthodontic, restorative, and craniomandibular disorder patients, because finding the correct diagnosis is crucial for the development of the optimum treatment strategy as well as for the application of the appropriate treatment. This book illustrates suecessfully a range of complex anatomic conditions involving the maxillofacial structures through the clever use of high-quality illustrations and diagnostic images.

Nevertheless, rather than recommending diagnostic imaging as a routine procedure, the authors correctly point out that diagnostic imaging is best applied when there is a likelihood of benefiting the patient. The potential value of the use of imaging for a patient is most often determined during the physical examination and history taking. To achieve the full value of diagnostic imaging, the clinician is required to develop specific imaging goals, to select the appropriate imaging modalities, to develop an imaging protocol, and to interpret the resultant image(s). The ideal imaging solution is one which meets the clinically derived imaging goals while maintaining the lowest achievable patient risk and patient cost. The authors discuss and illustrate the most common imaging modalities available today.

Dr Bumann and Dr Lotzmann applied a "systems" approach to facilitate understanding of the functional or biomechanical relationships between the craniomandibular structures, including the jaws, teeth, muscles, and temporomandibular joints. This type of approach would seem to be a must for all clinicians interested in the restoration of occlusion or in the diagnosis and management of selected craniomandibular disorders.

This textbook illustrates a wide range of maxillofacial, musculoskeletal, and articular conditions that may be associated with crandiomandibular disorders. I was intrigued by the proposed functional analysis which produces selected diagnostic data about intracapsular conditions of the temporomandibular joints that until now have been the exclusive domain of diagnostic imaging.

The authors have created a well-illustrated textbook, detailing many of the biomechanical aspects of craniomandibular disorders. The imaging portions alone would make this a valuable reference text for all practitioners trying to understand or diagnose patients with craniomandibular disorders.

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Foreword

Craniomandibular disorders are a group of disorders that have their origin in the musculoskeletal structures of the masticatory system. They can present as complicated and challenging problems. Almost all dentists encounter them in their practices. In the early stages of the development of this field of study the dental profession felt that these disorders were primarily a dental problem and could most often be resolved by dental procedures. As the study of craniomandibular disorders evolved we began to appreciate the complexity and multifactorial nature that makes these disorders so difficult to manage. Some researchers even suggested that these conditions are not a dental problem at all. Many clinicians, however, recognize that there can be a dental component with some craniomandibular disorders and when this exists the dentists can offer a unique form of management that is not provided by any other health professional. Dentists therefore need to understand when dental therapy is useful for a craniomandibular disorder and when it is not. This understanding is basic to selecting proper treatment and ultimately achieving clinical success, This is the greatest challenge faced by all dentists who manage patients with craniomandibular disorders.

The purpose of this atlas is to bring together information that will help the practitioner better understand the patient's problem thereby allowing the establishment of the proper diagnosis. A proper diagnosis can only be determined after the practitioner listens carefully to the patient's description of the problem and past experiences (the History) followed by the collection of relative clinical data (the Examination). The interpretation of the history and examination findings by the astute practitioner is fundamental in establishing the proper diagnosis. Determining the proper diagnosis is the most critical factor in selecting treatment that will prove to be successful. In the complex field of craniomandibular disorders misdiagnosis is common and likely the foremost reason for treatment failure.

Dr. Alex Bumann and Dr. Ulrich Lotzmann have brought together a wealth of information that will help the practicing dentist interested in craniomandibular disorders. This atlas provides the reader with techniques that assist in the collection of data needed to establish the proper diagnosis, This atlas brings together both new and old concepts that should be considered when evaluating a patient for craniomandibular disorders. Some of the old techniques are well established and proven to be successful. Some of the newer techniques are insightful and intuitive, and will need to be further validated with scientific data,

In this atlas the authors introduce the term "manual functional analysis" as a useful method of gaining additional information regarding mandibular function. They have developed these techniques to more precisely evaluate the sources of pain and dysfunction in the craniomandibular structures. Each technique is well illustrated using clinical photographs, drawings and, in some instances, anatomical specimens. Elaborate, well thought out, algorithms also help the reader interpret the results of the mandibular function analysis techniques. Although these techniques are not fully documented, they are conservative, logical, and will likely contribute to establishing the proper diagnosis. The authors also provide a wide variety of methods, techniques and instrumentations for the reader to consider.

This atlas provides an excellent overview of the many aspects that must be considered when evaluating a patient with a craniomandibular disorder. Appreciating the wealth of information presented in this atlas will certainly assist the dentist in gaining a more complete understanding of craniomandibular disorders. It will also guide the practitioner to the proper diagnosis. I am sure that the efforts of Dr. Bumann and Dr. Lotzmann will not only improve the skills of the dentists, but also improve the care of patients suffering with craniomandibular disorders. My congratulations to these authors for this fine work,

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Preface

Medicine and dentistry are continuously evolving, due largely to the influences and interactions of new methods, technologies, and materials. Partly because of outdated testing requirements, our students can no longer adequately meet the increasing demands these changes have placed on a patient-oriented education. With limited classroom and clinic time and an unfavorable ratio of teachers to students, the complex interrelations within the area of dental functional diagnosis and treatment planning are precisely the type of subject matter that usually receives only perfunctory explanation and demonstration in dental school. Consequently, recent dental school graduates are obliged to compensate for deficiencies of knowledge in all areas of dentistry through constant continuing education. And so the primary purpose of this atlas is to provide the motivated reader with detailed information in the field of dental functional diagnosis by means of sequences of illustrations accompanied by related passages of text. The therapeutic aspects are dealt with here only in general principles. Diagnosis-based treatment will be the subject of a future book.

The method of clinical functional analysis described in detail in this atlas is based largely on the orthopedic examination techniques described earlier by Cyriax, Maitland, Mennell, Kalternborn, Wolff, and Frisch. Hansson and coworkers were the first to promote the application of these techniques to the temporomandibular joint in the late seventies and early eighties. In cooperation with the physical therapist G. Groot Landeweer this knowledge was taken up and developed further into a practical examination concept during the late eighties. Because the clinical procedures differ from those of classic functional analysis, the term "manual functional analysis" was introduced.

The objective of manual functional analysis is to test for adaptation of soft-tissue structures and evidence of any loading vectors that might be present. This is not possible through instrumented methods alone. The so-called "instrumented functional analysis" (such as occlusal analysis on mounted casts or through axiography) is helpful nevertheless for disclosing different etiological factors such as malocdusion, bruxism, and dysfunction. Thus the clinical and instrumented subdivisions of functional diagnostics complement one another to create a meaningful whole,

In recent years the controversy over "occlusion versus psyche" as the primary etiological element has become more heated and has led to polarization of opinions among teachers. But in the view of most practitioners, this seems to be of little significance. In an actual clinical case one is dealing with an individualized search for causes, during which both occlusal and psychological factors are considered,

Within the framework of a cause-oriented treatment of functional disorders one must consider that while the elimination of occlusal disturbances may represent a reduction of potential etiological factors, it may not necessarily lead to the elimination of symptoms. The reason for this is that there can be other etiological factors that lie outside the dentist's area of expertise.

Some readers may object to the fact that the chapters "Mounting of Casts and Occlusal Analysis" and "Instrumented Analysis of Jaw Movements" do not reflect the multitude of articulators and registration systems currently available. We believe that for teaching purposes it makes sense to present the procedural steps explained in these chapters by using examples of an articulator and registration system that have been commercially established for several years. This should not be interpreted as an endorsement of these instruments over other precision systems for tracing and simulating mandibular movements,

Fall 2002

Axel Bumann
Ulrich Lotzmann

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The physical therapist Gert Groot Landeweer deserves our special thanks for the many years of friendly and fruitful collaboration. Before his withdrawal from the team of authors he made a great impact on the contents of this atlas through numerous instructive professional discussions.

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Graphic artist Adrian Cornford has demonstrated his great skill in translating our sometimes vague sketches into instructive illustrations. For this we are grateful.

Our thanks are due also to Prof. Sandra Winter-Buerke who, in posing as our patient for the photographs demonstrating the manual functional analysis procedures, submitted to a veritable "lightning storm" of strobe flashes. She endured the tedious photographic sessions with amazing patience.

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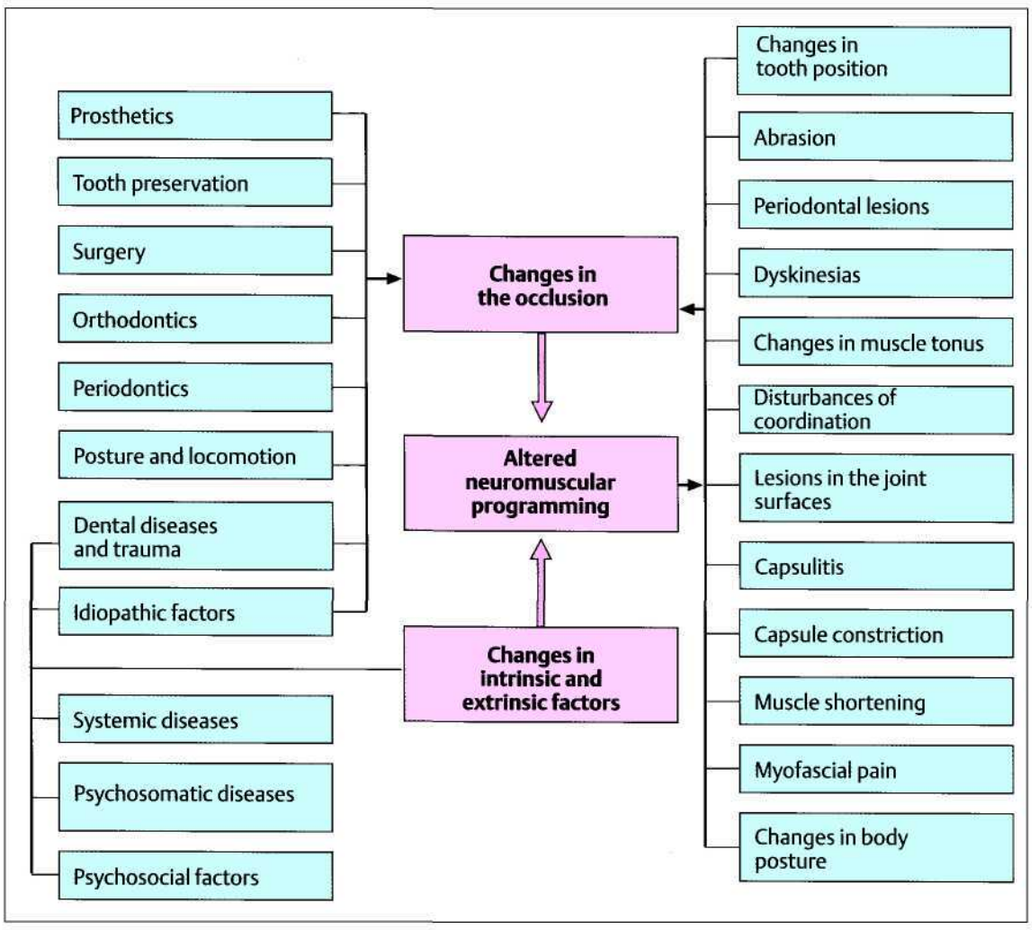
Introduction

The dental functional diagnostic procedure determines the functional condition of the structures of the masticatory system. For *patients with functional disturbances* it serves to arrive at a specific diagnosis. For medical and legal reasons, it is necessary for *all patients who are facing dental restorative or orthodontic treatment,* even for those who are assumed to have no malfunction. Often no connection can be established between the clinical findings discovered through conventional methods (testing of active movements and muscle palpation) and the symptoms reported by the patient. For that reason, specific manual examination methods for the masticatory system have gained prevalence during the past 15 years. These focus on the so-called loading vector and recognize the capacity of biological systems for adaptation and compensation. A cause-targeted treatment is then indicated only when the caregiver knows *which structures* are damaged *(loading vector*) and the cause of the damage (the *harmful influences*).



1 Possible causes and consequences of an altered occlusion
Idiopathic or iatrogenic alterations of the static or dynamic occlusion can influence the neuromuscular programming, and thereby affect other structures of the masticatory system. The same sequence of events can also be precipitated by intrinsic factors or other extrinsic factors. Usually during a clinical examination the changes listed in the right-hand column receive the most attention. But to plan a cause-targeted therapy it is necessary to determine what the specific causes of the altered neuromuscular programming are. A differentiated investigation protocol could set aside the old superficial philosophical discussion of the causes of functional disturbances within the masticatory system ("occlusion versus psyche") in favor of an individualized patient analysis.

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The Masticatory System as a Biological System

Every biological system, from a single cell to an entire organism, is continuously exposed to many influences. It overcomes these through two mechanisms:

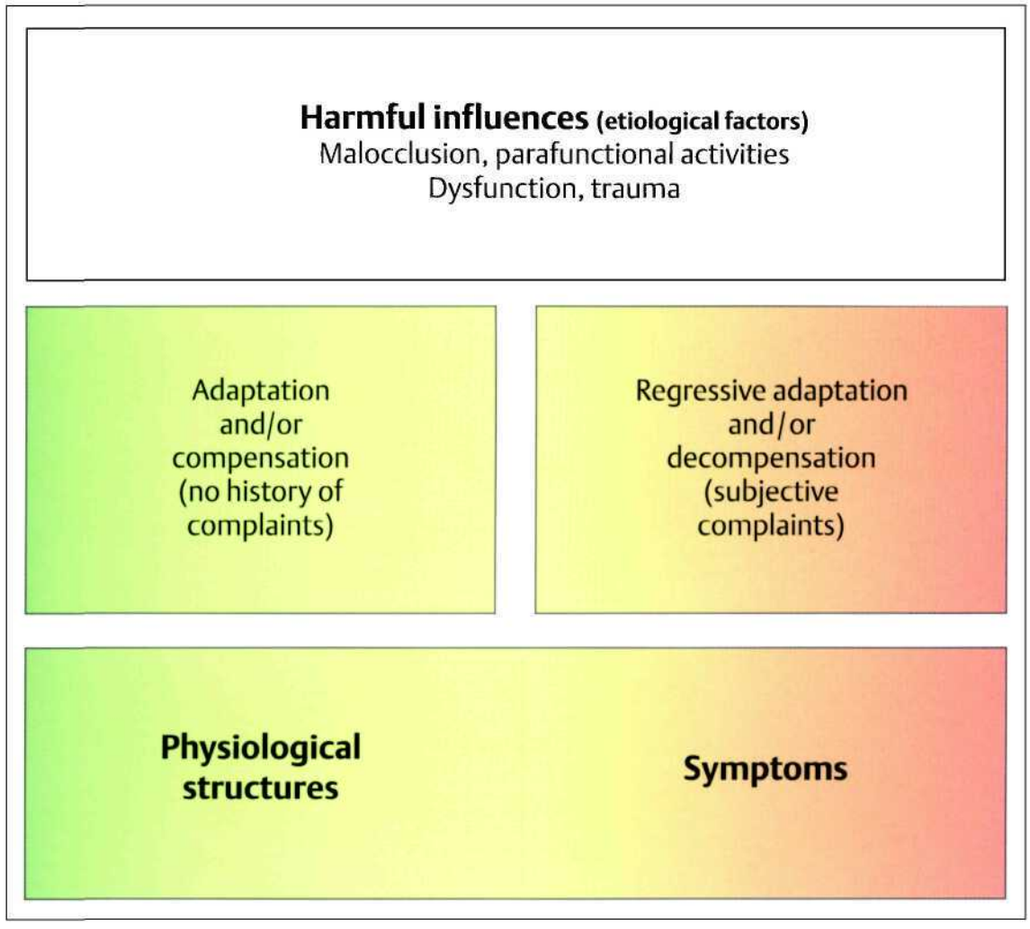
- adaptation as a reaction of the connective tissues;
- compensation as a muscular response to an influence (Hinton and Carlson 1997).

Influences on the one hand and the capacity for progressive adaptation on the other may achieve a physiologic state of equilibrium. If, however, the sum of harmful influences during a given period of time exceeds an individually variable threshold, or if the adaptability of a system becomes generally diminished, the system will fall out of equilibrium. This condition has been referred to as *decompensation* or *regressive adaptation* (Moffet et al. 1964) and is accompanied by more or less severe clinical symptoms. Regressive adaptation of bone can be seen on radiographs (Bates et al. 1993), and in soft tissues it is expressed as pain.

Because the adaptability of a system is primarily a genetic factor and decreases with increasing age, the most effective therapeutic measures are those aimed at the reduction of the harmful influences.

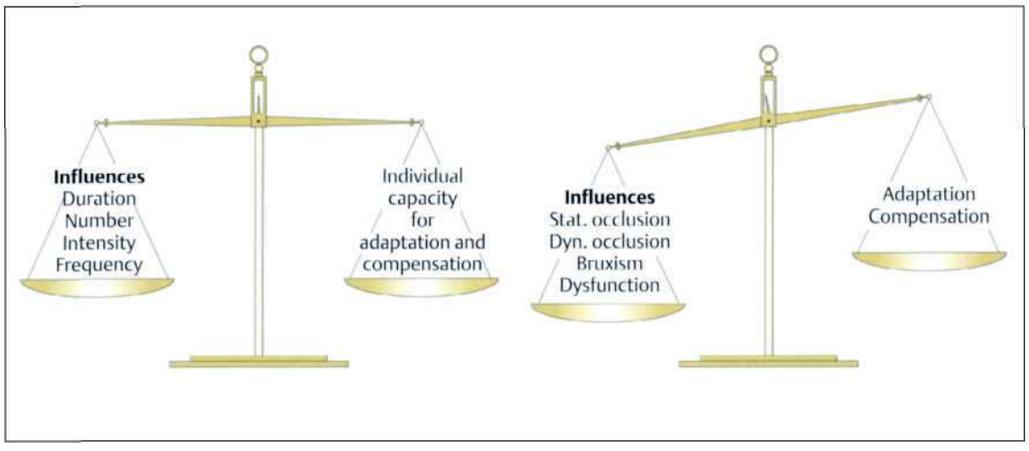
2 Fundamentals of the etiology of symptoms in the masticatory system

Every biological system is subjected to harmful influences of varying severity. The ones listed here represent only a selection of those which the dentist can demonstrate simply and repeatedly. These influences are assimilated by the system through progressive adaptation (connective-tissue reactions) or compensation (muscular reactions). As long as a system remains in this state, the patient will report no history of symptoms or functional disturbances. Only when the damaging factors exceed a certain threshold does regressive adaptation, or decompensation, accompanied by destructive morphologic changes and/or pain begin. By the time a patient comes to the dental office with symptoms, not only must severe influences already be present, but the mechanisms for adaptation and compensation must already be exhausted.



3 Equilibrium between influences and adaptation/ compensation

A healthy biological system can be compared with a balanced set of scales. The harmful influences on one side are countered by the individual's capacity for adaptation and compensation. The adaptive and compensatory mechanisms are genetically determined and therefore remain relatively constant, except for a gradual decline with age. For this reason, the equilibrium can only be disturbed by change on the side of the influences.



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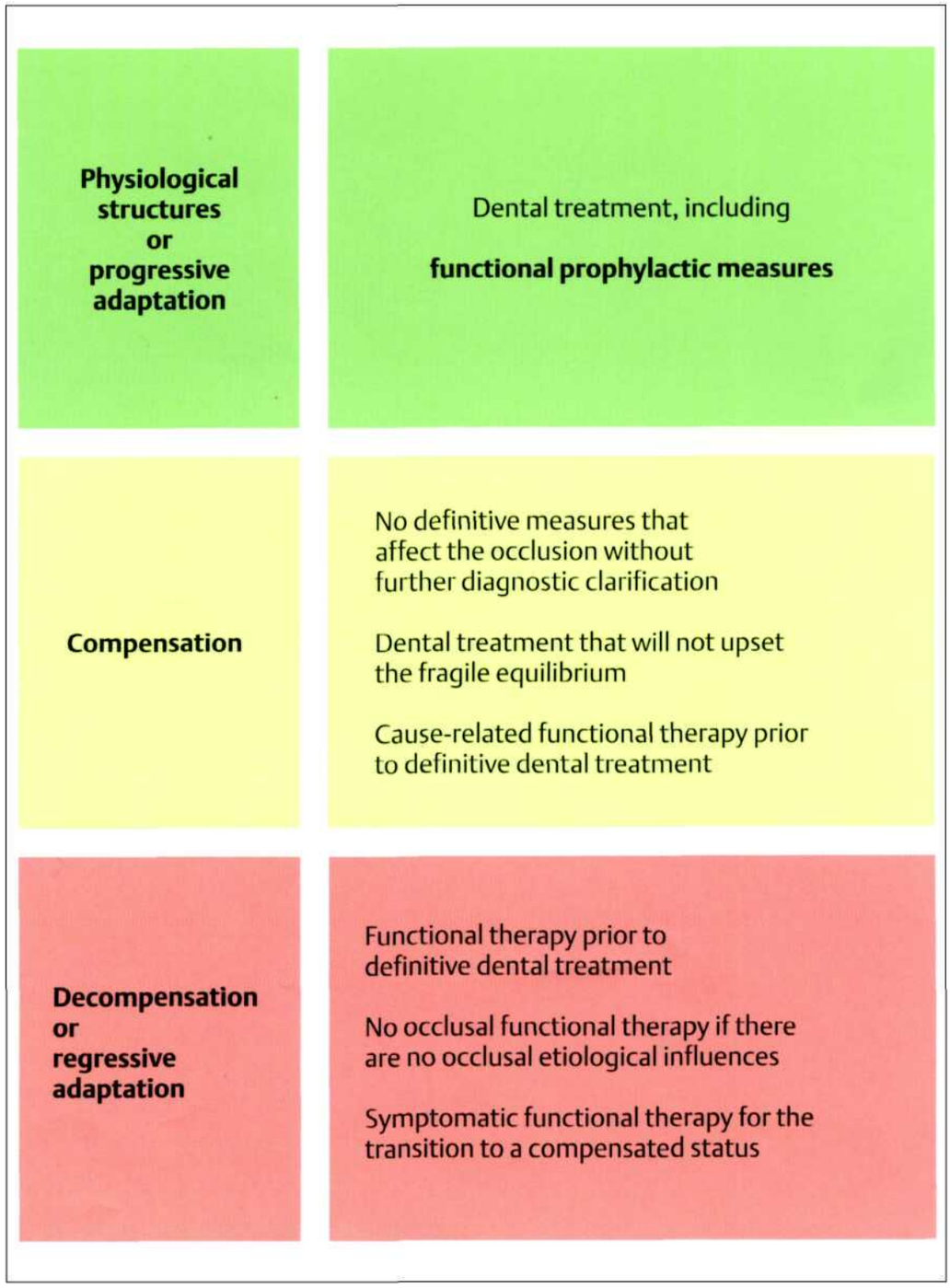
Progressive/Regressive Adaptation and Compensation/Decompensation

The patient population of a dental or orthodontic practice can be divided into three groups:

- "Green" group: The masticatory structures are either physiological or have undergone complete progressive adaptation. These patients have no history of problems, nor do they experience symptoms during the specific clinical examination.
- "Yellow" group: These patients have compensated functional disturbances and no history of problems. However, symptoms can be repeatedly provoked by specific manipulation techniques.
- "Red" group: Patients with complaints whose symptoms can be repeatedly provoked through specific examination methods suffer from a decompensated or regressively adapted functional disturbance.

In *young patients,* adaptation is based upon growth, modeling, and remodeling (Hinton and Carlson 1997). Modeling (= progressive adaptation) is the shaping of tissues by apposition and results in a net increase of mass. Remodeling (= regressive adaptation) is usually accompanied by a net decrease of mass. In *adults* adaptation depends primarily upon remodeling processes (de Bont et al. 1992).



4 Functional status of biological systems

A functional analysis should always be carried out before any dental restorative or orthodontic treatment is initiated. The patient's most urgent needs are determined by which group of the patient population he/she is classified under. For patients with complaints (red group) a functional analysis should be performed to arrive at a specific diagnosis and to determine whether or not treatment is indicated and possible, and if so whether it should be cause-related or symptomatic.

All other patients (green and yellow groups) have no history of complaints. If during a specific functional analysis with passive manual examination techniques, compensated symptoms can be repeatedly provoked in an otherwise symptom-free patient, the patient is classified in the yellow (caution!) group. Identification of these "yellow" patients is extremely important because of the therapeutic and legal implications. They make up between 10% and 30% of the patients in an orthodontic practice. Patients with compensated functional disturbances are also of special interest because tooth movement or repositioning of the mandible is always accompanied by stresses which increase the harmful influences on the system.

When faced with a compensated functional disturbance, the clinician has three basic options:

1. Referral of the patient because of the complexity of the problem.
2. Dental treatment without provoking decompensation. Here the dentist must be aware of the loading vector acting upon the system.
3. Treatment directed at the cause with subsequent definitive dental treatment monitored through ongoing functional analysis.

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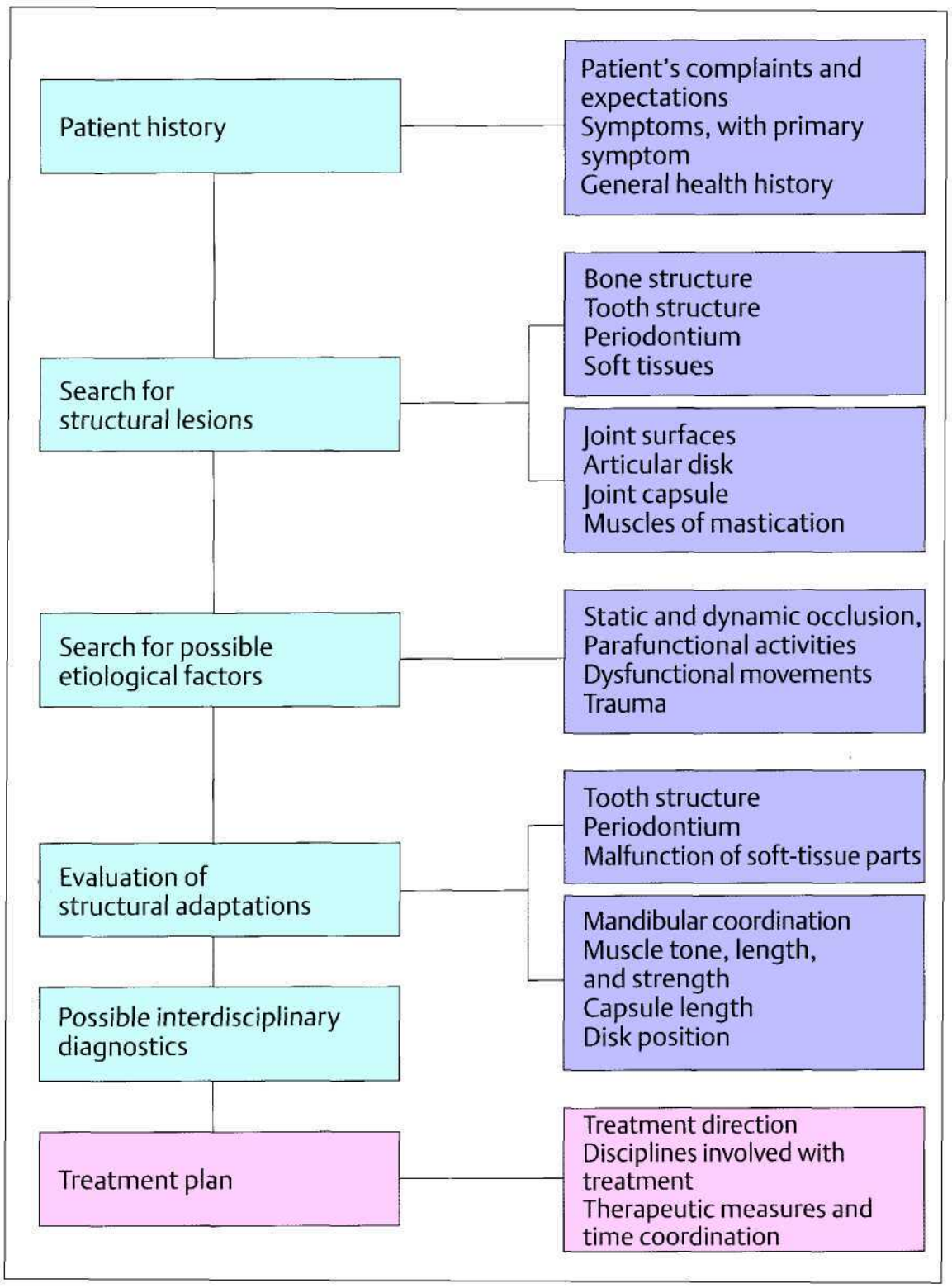
Functional Diagnostic Examination Procedures...

Besides a thorough case history, a modern treatment-oriented functional diagnostic concept is composed of three parts:

- Examination to determine the extent of destruction of the different structures of the masticatory system. This part determines conclusively whether or not there is a loading vector (= overloading of one or more structures in a specific direction).
- Treatment-oriented examination to reveal any structural adaptations (= progressive adaptations). Here thought must be given to distinguishing between progressive adaptation in the loaded structures and adaptation of the surrounding structures. As a rule, the former are desirable and require no treatment, whereas adaptations in the surrounding structures usually result in an increase of the load and restriction of movement. Adaptations of surrounding structures are always oriented in the direction of the loading vector and therefore impede treatment. Within the framework of an interdisciplinary treatment, it is the duty of the physical therapist to eliminate any adaptive conditions in the surrounding structures through manual therapy and measures to increase mobility. Without a permanent modification of habitual functional patterns, physical therapy will not be successful.

5 Schematic representation of the treatment-directed examination sequence

To establish a function-based, problem-oriented treatment plan, it is first absolutely necessary to gather specific information in a rigidly defined sequence. Our current concept has been tested and validated by more than 10 years of clinical experience. The three elements at its core are the reproducible determinations of destruction (= loading vector), structural compensations (= adaptations) and etiological factors (= influences). The first two elements require the examination techniques of manual functional analysis. At this time there is no practical alternative available to test for loading vectors and evidence of adaptations in the masticatory system. Because of their multiplicity and variety of origins, the influences can be only partially clarified within a dental practice. For this the dentist has at his/her disposal the techniques of clinical occlusal analysis and instrumented functional analysis (in the articulator). In functional diagnostics the latter serves only as a test of the influences and cannot provide conclusive information without knowledge of the individual loading vectors that may be present.



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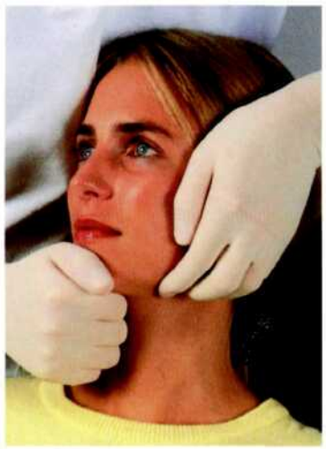
...and their Therapeutic Consequences

- The third part of the examination process seeks to identify all possible harmful influences, and for the dentist this is the most important part. It deals especially with finding evidence for causal relationships between any loading vector and the occlusion. The findings provide information as to whether or not the static and dynamic occlusions are *contributing to* the overloading of affected structures. In the discussion of whether treatment should be solely dental or interdisciplinary there are two basic points to consider: On the one hand, isolated treatment of the masticatory system also affects the structures that allow movement (Lotzmann et al. 1989, Gole 1993), while on the other hand, treatment of the movement apparatus may also resolve problems in the masticatory system (Makofsky and Sexton 1994, Chinappi and Getzoff 1996). Patients with chronic pain can benefit significantly from a thorough, specific, interdisciplinary treatment (Bumann et al. 1999).



1. Search for structural lesions

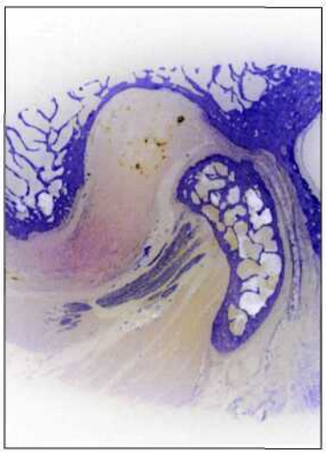
"What does the patient have?"

Dental primary diagnosis

Direction of the destructive loading (loading vector)
- Manual functional analysis
- Imaging procedures

6 Evaluation of the destruction
The extent of intraoral destruction is determined by the traditional dental primary diagnostic methods. Damage to the individual structures of the temporomandibular joint and the muscles of mastication can be detected only through manual functional analysis. In some cases additional imaging procedures are necessary.

Left: Example of a clinical examination technique (posterosuperior compression) to detect destructive changes in the masticatory system.



2. Evaluation of structural adaptation

"Are there any impediments to treatment?"

Direction of the impediment (restriction vector):
Evaluation of innervation, muscle tone, muscle strength, muscle length, capsule mobility, nonreducing disk displacement

7 Identification of the impediments
Identification of musculoskeletal impediments is very important for treatment planning. If existing impediments are not diagnosed, the treatment goal will be reached much later, if at all. Furthermore, the treatment result is likely to remain unstable.

Left: A histological slide shows anterior disk displacement with disk deformation as an example of an impediment in the anterior treatment direction.

3. Search for possible etiological factors

"Why does the patient have this symptom?"

Direction of potential influences (influence vectors):
- Patient history and inspection
- Clinical analysis of the occlusion
- Instrumented analysis of function

8 Identification of the influences
The search for causes is aided by asking why the symptom arose. From the dental point of view, the question arises as to whether the occlusion is associated in any way with the symptom or the loading vector (see p. 124ff). If this is not the case then the patient in question will not be helped by modifications of the occlusion.

Left: Example showing use of the Mandibular Position Indicator to help diagnose a static occlusal vector (see p. 128).

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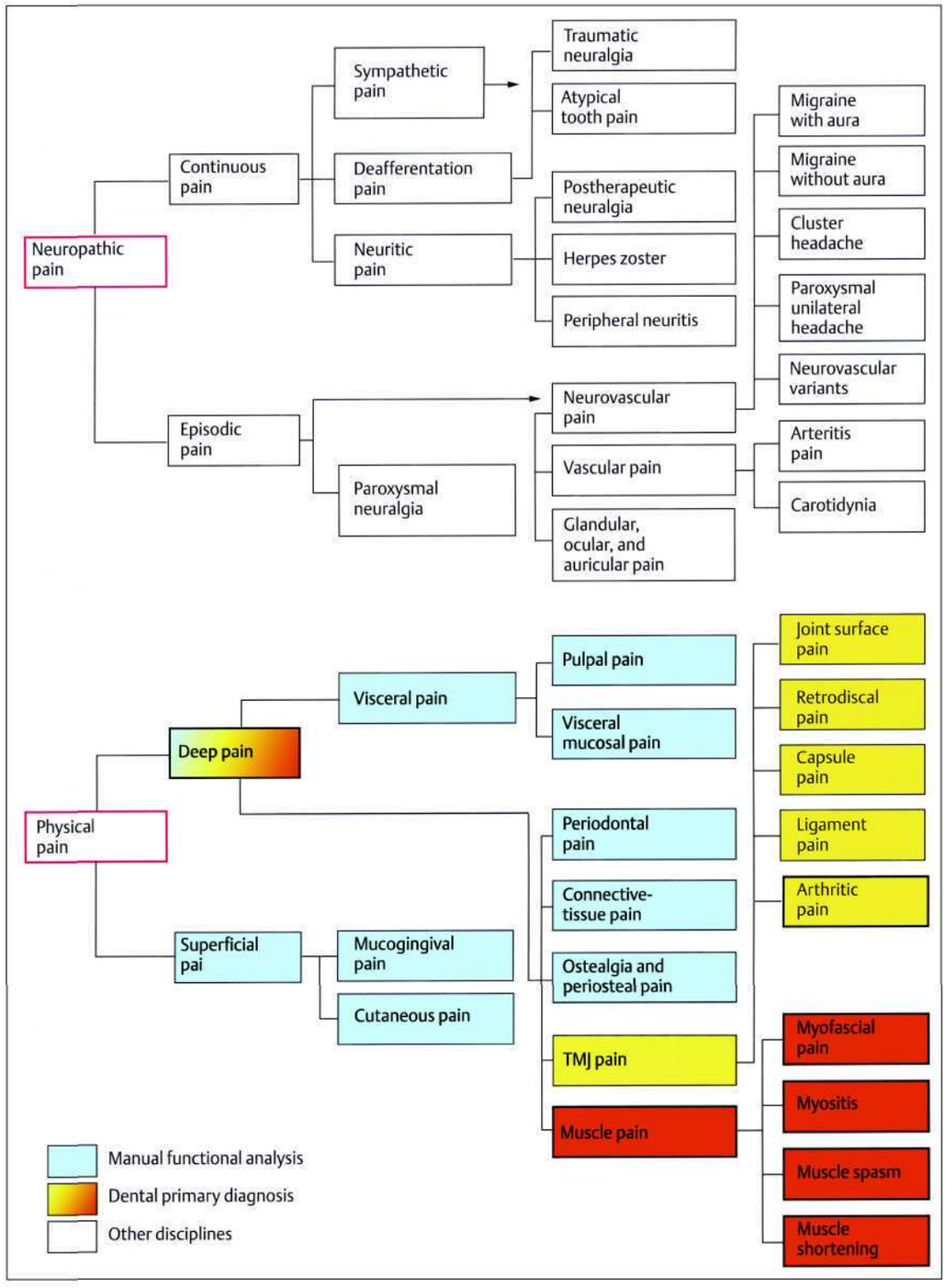
The Role of Dentistry in Craniofacial Pain

Polarizing discussions during the past 10 years have made the role of the dentist in diagnosing and treating pain in the head and neck region increasingly obscure rather than more clear. In the academic debate concerning the etiology—predominantly *psychological factors* versus predominantly *occlusal factors—the* practitioner facing the problem of treating a patient has been largely ignored. The argument of *multicausal genesis* was previously taken as an excuse to regard the multiple causes as an inseparable bundle rather than to dispel at least a certain amount of confusion by specifically testing the individual factors.

It is our opinion that every patient with head and neck pain should be seen by a dentist in order to clarify the following questions:

- Do the symptoms arise from a structure in the masticatory system (presence of a loading vector)?
- Is the loading vector related to the occlusion?
- Can the occlusion-related portion of the total loading vector be reduced with reasonable effort and expense?
- Would symptomatic treatment in the dental office be reasonable?



9 Differential diagnosis of head and neck pains
A pain classification scheme modified from those of Bell (1990) and Okeson (1995). The colors of the backgrounds of the different diagnoses indicate which disorders are outside the realm of dental treatment and which require the inclusion of other disciplines for diagnostic assistance or for ruling out certain conditions. In addition, colors indicate which diagnoses can be arrived at through which steps in the dental examination.
As clearly shown by the overview, dentistry covers a significant part of the differential diagnosis of head and neck pain. This does not mean, however, that dentistry should be the leading discipline in treating every case of head and neck pain. There are, for example, areas in which the dentist cannot intervene with primary cause-related treatment, or even with interdisciplinary secondary support.
The primary goal of a tissue-specific diagnostic process for identification of loading vectors is to differentiate between conditions that can and cannot be treated by a dentist. Except in the latter instance, the decision must then be made whether dentistry is to provide the sole treatment of the diagnosed conditions or is to be part of an interdisciplinary approach.

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Primary Dental Evaluation

The dental examination is the *conditio sine qua non* for arriving at a correct diagnosis and effective dental treatment plan. Every case in which a patient complains of craniofacial pain requires a thorough gathering of information on the status of the teeth, periodontium and mucous membranes, even when there appears to be no connection between the reported complaints and the "typical" toothache. Beware of a superficially conducted "quick diagnosis" which always increases the risk that essential findings and secondary factors will be overlooked, incorrectly evaluated, or forgotten, especially when they seem to bear no apparent relationship to the patient's reported symptoms.

Strictly speaking, the examination begins with the first visual and verbal contact with the patient (physiognomy, skin and facial coloration, posture, gait, speech etc.) Even if not all the information is germane to the dental diagnosis, it is the dentist's duty to identify, to the best of his or her ability, any symptoms that might indicate a systemic illness and to motivate the patient to seek an evaluation from an appropriate specialist (Kirch 1994).

There are various techniques for eliciting and documenting a case history. It is recommended that patients first be allowed to begin describing their history of illnesses in their own words. Because the description of previous illnesses usually proceeds at an irregular pace, after a period of time determined on an individual basis, the caregiver should politely interrupt the patient's monologue and conduct the consultation further by asking concrete questions concerning the primary and secondary symptoms. Under no circumstances should these questions be leading or suggestive. The diagnosis, treatment plan, and success of the treatment are dependent upon correct interpretation of the findings and therefore upon the knowledge and experience of the clinician. A frequent mistake is the failure to discuss not just the physical, but also psychological conditions as possible etiological factors, especially in cases with ambiguous, indistinctly localized complaints in the face and jaws (Marxkors and Wolowski 1998).

Patient history What are your symptoms?	
What is your main symptom?	
What do you expect from me?	

10 Special patient-history excerpt from the questionnaire "Manual Functional Diagnosis"

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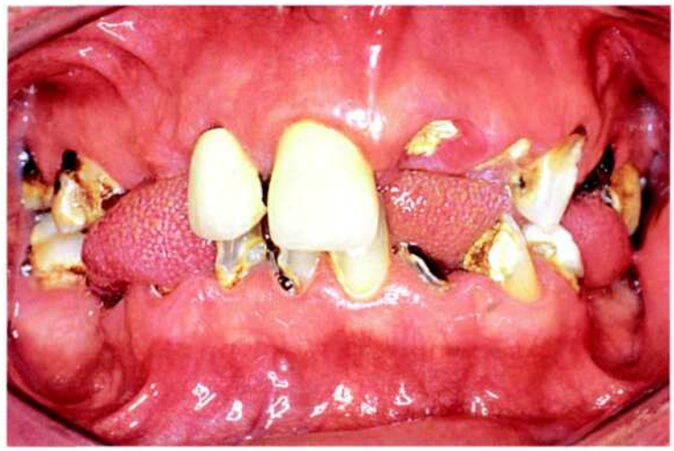
Findings in the Teeth and Mucous Membrane

The intraoral evaluation includes in particular:

- careful evaluation of the mucous membranes
- determination of the status of the teeth, including detection of caries and periodontal disease
- a search for signs of occlusal disturbances and parafunction (abrasion, wedge-shaped defects, enamel cracks and fractures, and increased tooth mobility) and
- evaluation of the function of fixed and removable partial dentures and orthodontic appliances.

Numerous diseases, both local and systemic, reveal themselves through changes in the oral mucosa. Therefore the lips, entire vestibule, alveolar ridge, hard and soft palate, tonsils, pillars of the fauces, oropharynx, floor of the mouth, and tongue, including its ventral surface, must be carefully examined for any rashes, discolorations, coatings, or indurations (Veltman 1984). Inflammation localized within the pulp, periodontium, or mucosa can cause pain, varying in degree from light to excruciating, to radiate to the jaws, cheeks, eyes, or ears. The pain can be accompanied secon-

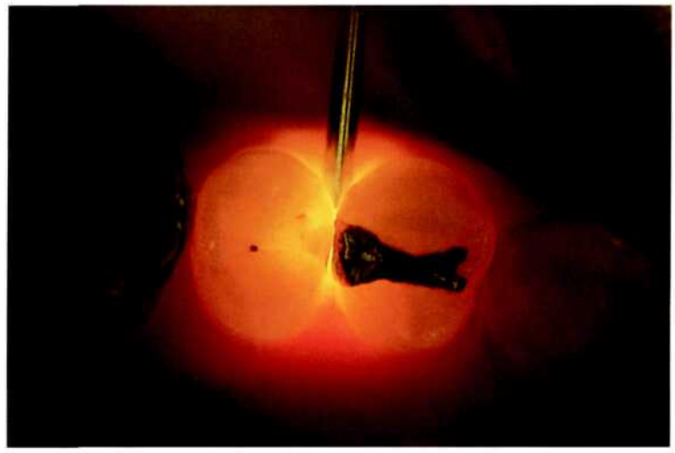
11 Intraoral inspection
Dentition of a 35-year-old patient exhibiting severe damage from caries and periodontal disease. There is diffuse radiating pain in the right half of the face.



12 Diagnosis of caries
Transillumination by placing a cold light probe (by EC Lercher) interproximally reveals caries extending into the dentin of the second premolar as evidenced by the increased opacity of the carious tooth structure.

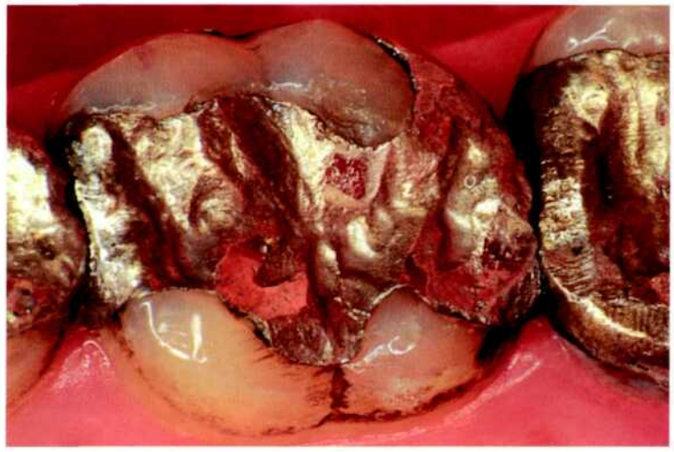
Right: The same region as in the left photograph under regular lighting. The proximal caries on the mesial of the second premolar cannot be seen without the help of a diagnostic aid.

Contributed by K. Pieper



13 Fractured filling and fractured dentin
A functionally inadequate filling with poor marginal integrity is the cause of dentinal pain.

Right: The dentinal fracture on this first premolar was detected only after the occlusal base under the filling was removed. The patient had been experiencing paroxysmal pain in this area upon occlusal loading.



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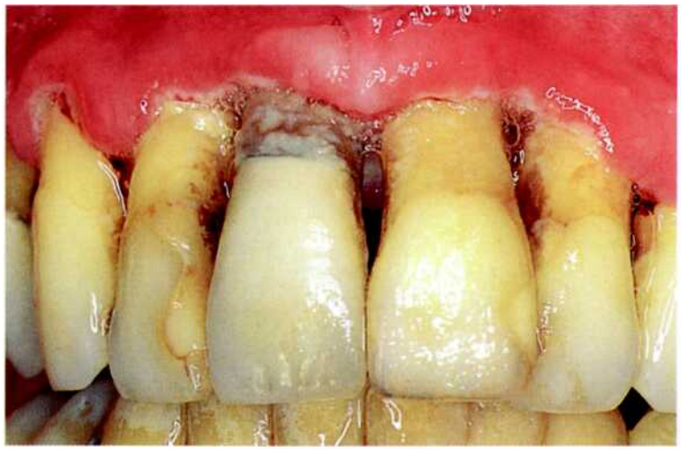
darily by discomfort in the joints and muscles and by reduction of lower jaw mobility. In these cases, treatment is focused upon elimination of the primary cause of the pain. In those cases in which it is difficult to differentiate among the overlapping symptoms, selective introduction of local anesthesia as a diagnostic tool can help to identify the source of the pain and the regions to which it radiates.

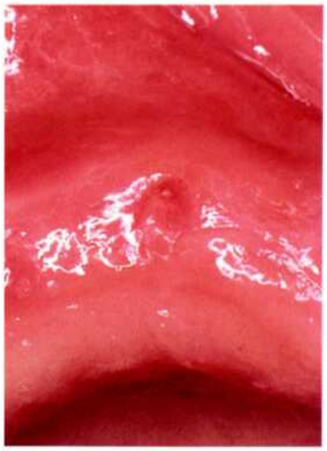
With mucosal lesions of unknown origin or ulcerations that fail to heal after the presumed cause is removed, a malignant tumor should be suspected. Mistaking an oral carcinoma for a pressure sore from a denture is tragic and inexcusable ! In case of doubt, a specialist should be consulted. A prolonged course of functional therapy for the masticatory system should be complemented by a repeated dental examination of the mucosa and dentition for the early detection of any new pathology. Normally, during the initial patient evaluation the intraoral examination is supplemented by a radiographic survey (orthopantogram, periapical films).

Caveat: The dentist has an absolute duty to organize and preserve the results of the examination.



14 Periodontal findings
Acute necrotizing gingivitis (periodontitis) in a patient with full-blown AIDS.

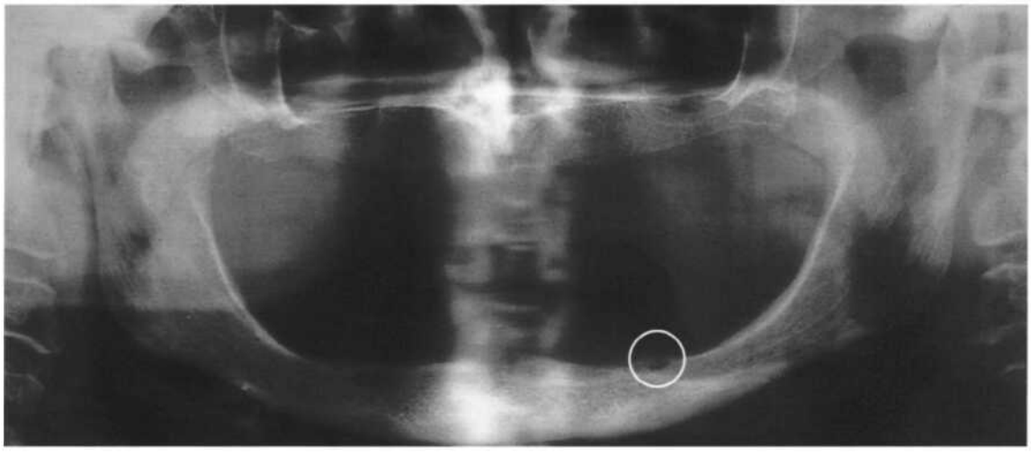
Left: Pronounced localized gingival recession with severe hypersensitivity at the neck of the tooth.



15 Traumatic mucosal defects
Left: The same region as shown in the center photograph. The mucosal defect caused a neuralgia-like pain radiating to the right eye.

Center: The mucosal lesion was caused by occlusion of the opposing tooth against the alveolar ridge.

Right: Iatrogenic ulcer in the midline at the transition from hard to soft palate as the result of a posteriorly overextended denture border.



16 Radiographic findings
This panoramic radiograph shows extensive atrophy of the edentulous mandible with exposure of the left mental foramen (circled). Mechanical irritation of the mental nerve by the lower denture caused pain encompassing the left temporomandibular joint region.

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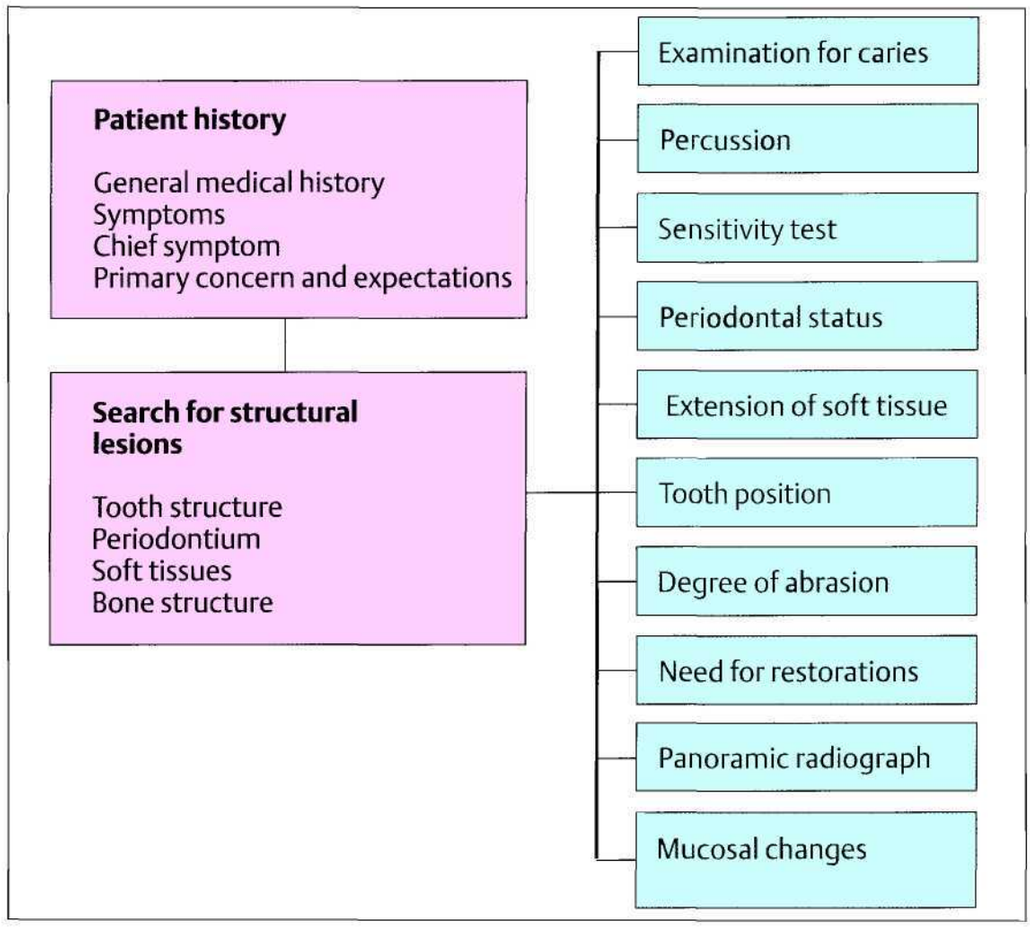
Overview of Dental Examination Techniques

Before beginning the specific functional diagnostic procedure for a patient with pain in the jaws and face or with limited mandibular mobility, all possible intraoral causes for the reported symptoms should be investigated. The goal of conventional dental evaluation is to rule out periodontal and dental structures, as well as intraoral hard and soft tissues, as the source of the pain. The process is similar in principle to manual functional analysis, in that it should be possible to repeatedly initiate or intensify the symptom through probing and/or judicious loading of the tissues. Patient history, extraoral and intraoral inspection (e.g. for trauma, redness, swelling) and radiographic interpretation (e.g. inflammatory processes) complete the primary dental examination. If there is no significant pathology present that could explain the patient's problem, or if the patient's pain cannot be elicited during the primary dental examination, initial dental treatment procedures are not indicated. Blind action is to be avoided.



17 Overview of dental examination techniques
For patients with acute or chronic jaw and facial pain, a primary dental diagnosis is always performed before the joint-specific examination techniques are carried out.

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Anatomy of the Masticatory System

A rational clinical examination of the masticatory system requires a sound basic knowledge of the anatomy. As will become clear later in the discussion of clinical examination procedures, the foundation of manual functional analysis is a good knowledge of the functional anatomy. In this chapter the individual anatomical structures will be described in a sequence corresponding to the later examination steps and separated according to their physiology and stages of adaptation and compensation. Knowledge of the different progressive and regressive tissue reactions is not only relevant to the diagnostic interpretation of the findings, but it also decisively influences the treatment strategy. The division into physiological, compensated, and adapted masticatory systems is necessary not only for diagnostic purposes but, more importantly, for the determination of what treatment goals are attainable for the individual.

The human jaw articulation is a so-called secondary joint (Gaupp 1911) because it developed separately and not as a modification of a primary joint (Dabelow 1928). The essential morphogenetic events in the formation of the joints of the jaw occur between the seventh and twentieth embryonic weeks (Baume 1962, Furstman 1963, Moffet 1957, Baume and Holz 1970, Blackwood et al. 1976, Keith 1982, Perry et al. 1985, Burdi 1992, Klesper and Koebke 1993, Valenza et al. 1993, Bach-Petersen et al. 1994, Ögütcen-Toller and Juniper 1994, Bontschev 1996, Rodriguez-Vazquez et al. 1997). The critical period for the appearance of malformations in the joints of the jaw is reported differently in different studies. According to Van der Linden et al. (1987) it is between the seventh and eleventh weeks, according to Furstman (1963) between the eighth and twelfth weeks, and according to Moore and Lavelle (1974), between the tenth and twelfth weeks.

Formation of the bony mandible begins in weeks 6-7 lateral to Meckel's cartilage in both halves of the face. A double anlage of Meckel's cartilage is extremely rare (Rodriguez-Vazquez et al. 1997). Its effect on embryonic development is unknown. By about the twelfth week the two palatal processes have united at the midline to complete the separation of the oral and nasal cavities. At the same time, bony anlagen of the maxilla form in the region of the future infraorbital foramina. These spread rapidly in a horizontal direction and progressively fill the space between the oral cavity and the eyes. When the crown-rump length (CRL) is approximately 76 mm (weeks 10-12), the anlagen of the maxillary bone, the zygomatic bone, and the temporal bone come into contact with one another. Ossification of the base of the cranium and of the facial portion of the skull follows in a strict, genetically determined sequence (Bach-Petersen et al. 1994). First to ossify is the mandible, followed by the maxilla, medial alar process of the sphenoid bone, frontal bone, zygomatic bone, zygomatic arch, squamous part of the occipital bone, greater wing of the sphenoid bone, tympanic bone, condyles of the occipital bone, lesser wing of the sphenoid bone, and finally the dorsolateral portion of the sphenoid bone.

In an embryo with a CRL of approximately 53 mm the coronoid process and the condylar process can already be clearly distinguished from one another. The biconcave form of the articular disk becomes apparent at a CRL of 83 mm. In histological preparations, fibers of the pterygoid muscle can also be seen streaming in quite early (Radlanski et al. 1994). At this stage the superior belly of the lateral pterygoid muscle inserts at the middle and central third of the disk and the lower belly inserts at the condyle (Merida-Velasco et al. 1993). At a CRL of 95 mm all structures of the temporomandibular joint can be clearly identified and thereafter undergo no essential change other than an increase in size (Bontschev 1996).

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Embryology of the Temporomandibular Joint and the Muscles of Mastication

During the development of the temporomandibular joint the *articular fossa* is the first structure to become recognizable. This occurs during weeks 7-8 (Burdi 1992). It first appears as a concentration of mesenchymal cells over an area of tissue that later differentiates into disk and capsule. Between the tenth and eleventh weeks the fossa begins to ossify. Development of the cortical layer and the bony trabeculae is more rapid in the fossa than in the condyle. The fossa develops first as a protrusion on the original site of the zygomatic arch and grows in a medial-anterior direction (Lieck 1997). At the same time the articular eminence begins to develop. The *condyle,* at first cartilaginous, develops between the tenth and eleventh weeks from an accumulation of mesenchymal cells lateral to Meckel's cartilage (Burdi 1992). Enchondral ossification progresses apically, creating a bony fusion with the body of the mandible. After the fifteenth week the chondrocytes have differentiated enough so that the cartilage already exhibits the typical postnatal organization of structure (Perry et al. 1985), and from the twentieth prenatal week onward only the superficial portion of the process consists of cartilage.

Joint development

18 Tenth week

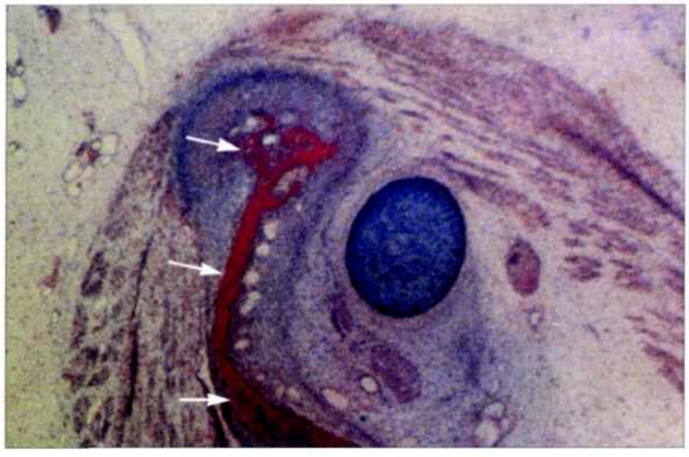
A histological section in the frontal plane showing the condylar process (1) and Meckel's cartilage (2) at the tenth week of embryonic development.

The condylar process is rounded over and surrounded by a layer of especially dense mesenchyme (arrows). It lies lateral to Meckel's cartilage. The fast-growing dorsocranial portion of the accumulation of cartilage cells creates the distinctive shape of the condyle.

19 Eleventh week

Above: A human temporomandibular joint in the frontal plane at the eleventh week of development. This represents the same area shown in Figure 19 only 10 days further along. The condylar process is beginning to ossify (arrows). At this time the swallowing reflex is also developing and is accompanied by the formation of secondary cartilage in the temporomandibular joint (Lakars 1995).

Contributed by R. Wurgaft Dreiman



Below: Sagittal section of a temporomandibular joint at the same stage of development. Above the condyle (1) is a distinct concentration of mesenchymal cells (arrows). At its inferior region the mesenchymal thickening is already beginning to detach from the condyle as the lower joint space forms. During this time the first collagen fibers of the disk become visible and increase greatly in number until the twelfth week.

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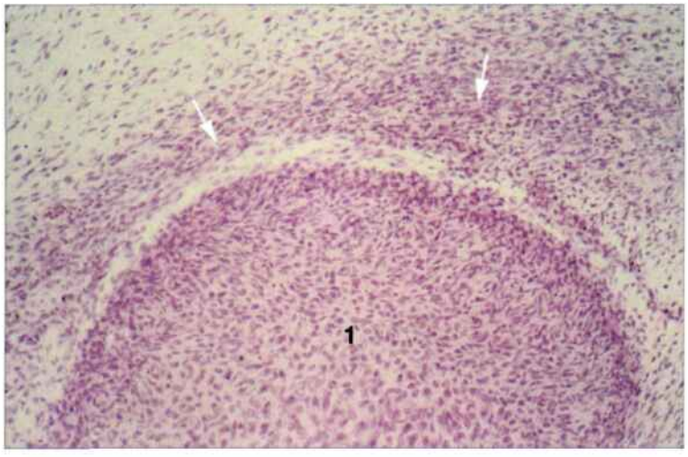

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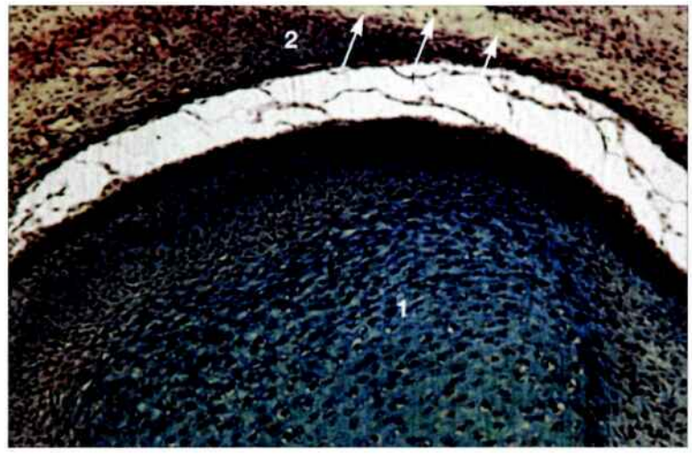
The *articular disk* can first be identified after 7.5 weeks in utero as a horizontal concentration of mesenchymal cells (Burdi 1992). Between weeks 19 and 20 its typical fibrocartilaginous structure is already evident.

The joint *capsule* first appears between weeks 9 and 11 as thin striations around the future joint region (Burdi 1992). After 17 weeks the capsule is clearly demarcated, and after 26 weeks all of its cellular and synovial parts are completely differentiated.

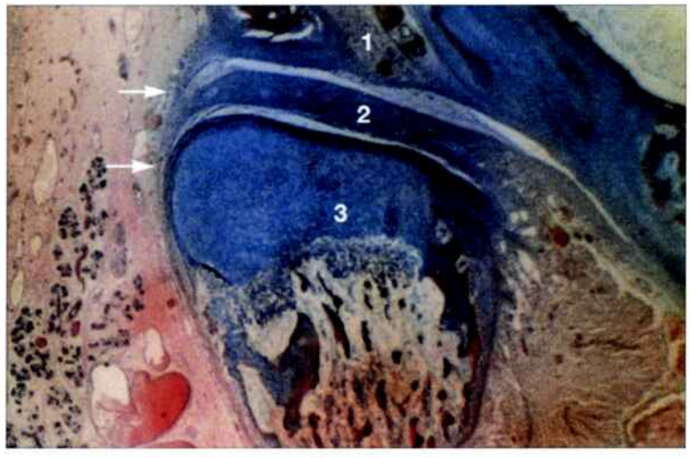
In weeks 9-10 the *lateral pterygoid muscle* is recognizable with its superior head inserting on the disk and capsule and its inferior head inserting on the condyle. Fibers of the *masseter and temporal muscles* also insert on the disk (Merida Velasco et al. 1993).

During the tenth week the first *blood vessels* become organized around the joint. The disk has small blood vessels only at its periphery and is itself avascular (Valenza et al. 1993). Branches of the *trigeminal* and *auriculotemporal nerves* are clearly visible in the twelfth week (Furstman 1963). The numerous nerve endings that can still be seen in the disk in the twentieth week diminish rapidly so that after birth the disk is no longer innervated (Ramieri et al. 1996).



20 Fourteenth week
Sagittal section of a human disk-condyle complex. A distinct joint space has now formed between the condyle (1) and the disk (2). Above the disk the temporal blastema begins to split away to form the upper joint space (arrows). The cartilage of the condyle is increasingly replaced by bone from below. However, remnants of the original cartilage remain in the neck of the condyle until past puberty.

21 Sixteenth week
Horizontal section of a human temporomandibular joint during the sixteenth week of embryonic development. Insertion of the lateral pterygoid muscle (1) onto the condyle (2) can be clearly identified. In agreement with reports in the literature (Ögütcen-Toller and Juniper 1994, Ögütcen-Toller 1995), the discomaleolar ligament (arrows) runs from the joint capsule through the tympanosquamosal fissure to the malleus (3) as an extension of the muscle.



22 Eighteenth week
Frontal section through a human temporomandibular joint in the eighteenth week of embryonic development. The fossa (1), disk (2) and condyle (3) are completely developed and from now on will experience only an increase in size. The joint capsule (arrows) can also be clearly identified. The cartilaginous condyle will ossify further. Distribution of cartilage at this stage indicates that future growth will be primarily in the laterosuperior direction.

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Development of the Upper and Lower Joint Spaces

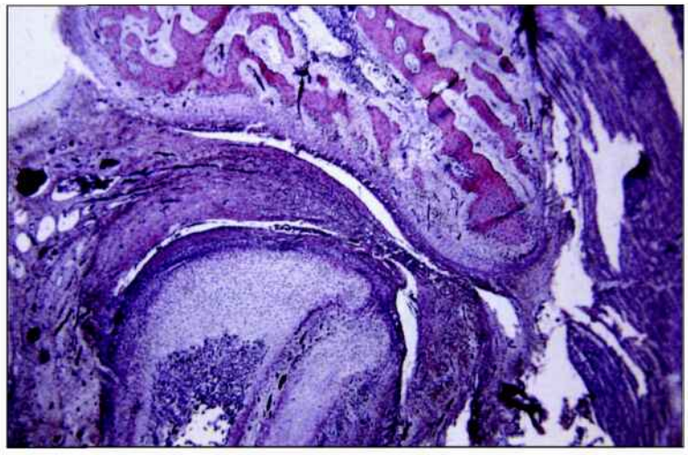
The upper and lower joint spaces arise through the formation of multiple small splits in the dense mesenchyme from which the condyle, disk, and fossa arose previously.

The *lower joint space* appears first at about the tenth week (50-65 mm CRL), but later the upper joint space overtakes it in its development (Burdi 1992). At first the space is extensively compartmentalized, and it is only later that the individual cavities merge (Bontschev 1996). The lower joint space lies close to the embryonic condyle.

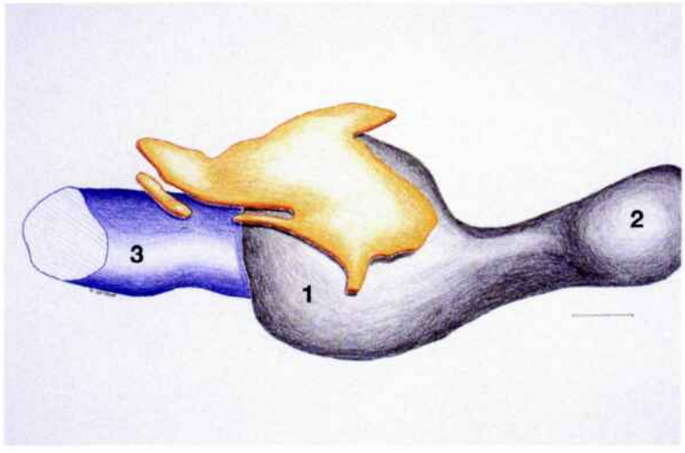
The upper joint space appears after about the twelfth week (60-70 mm CRL) and spreads posteriorly and medially over Meckel's cartilage with its contour corresponding to that of the future fossa. After week 13 the lower joint space is already well formed as the upper joint space continues to take shape. From its beginning, the upper joint space has fewer individual islands of space and grows more rapidly than the lower joint space. After week 14 both joint spaces are completely formed. During weeks 16-22 the lumens of the chambers become adapted to the contours of the sur-

Joint development

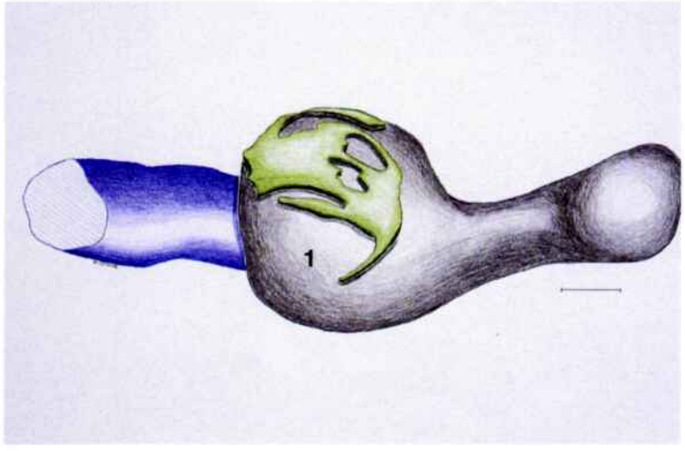
23 Twenty-sixth week
Completely formed human temporomandibular joint with physiolgical lower and upper joint spaces. Trabecula-like structures can be identified in both joint spaces where the disk has not yet separated completely from the temporal and condylar portions. At present it has not been conclusively determined whether or not this type of incomplete separation could be one cause of disk adhesions.



24 Development of the joint spaces
Above: Three-dimensional reconstruction from a series of histological sections of the developing joint space (yellow) of a right temporomandibular joint. In the center of the picture is the condyle (1); to the right of it lies the coronoid process (2). To the left behind the condyle is Meckel's cartilage (3). The upper joint space arises approximately 2 weeks after the lower.



Below: Three-dimensional reconstruction of the lower joint space (green) of the same joint. Initially the mesenchyme in the condylar region (1) is still uniformly structured, but in weeks 10-12 it begins to tear in several places mesial and distal to the condyle. The resulting clefts run together to form the lower joint space. A region of concentrated mesenchyme remains between the two joint spaces, from which the fibrocartilaginous articular disk is later formed.



Contributed by *R.j. Radianski*
(Figs. 23-25)

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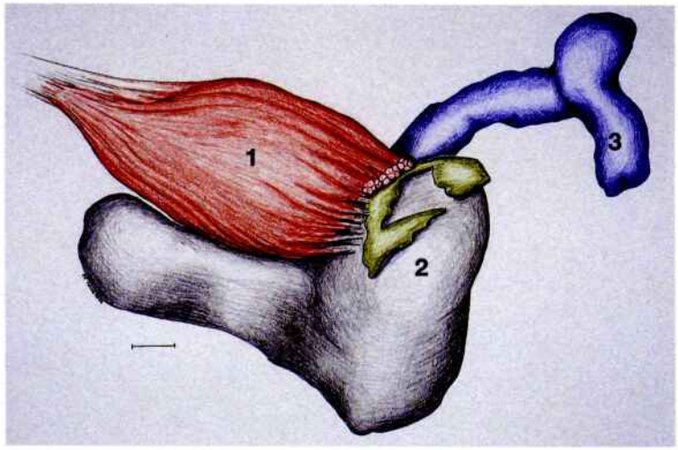
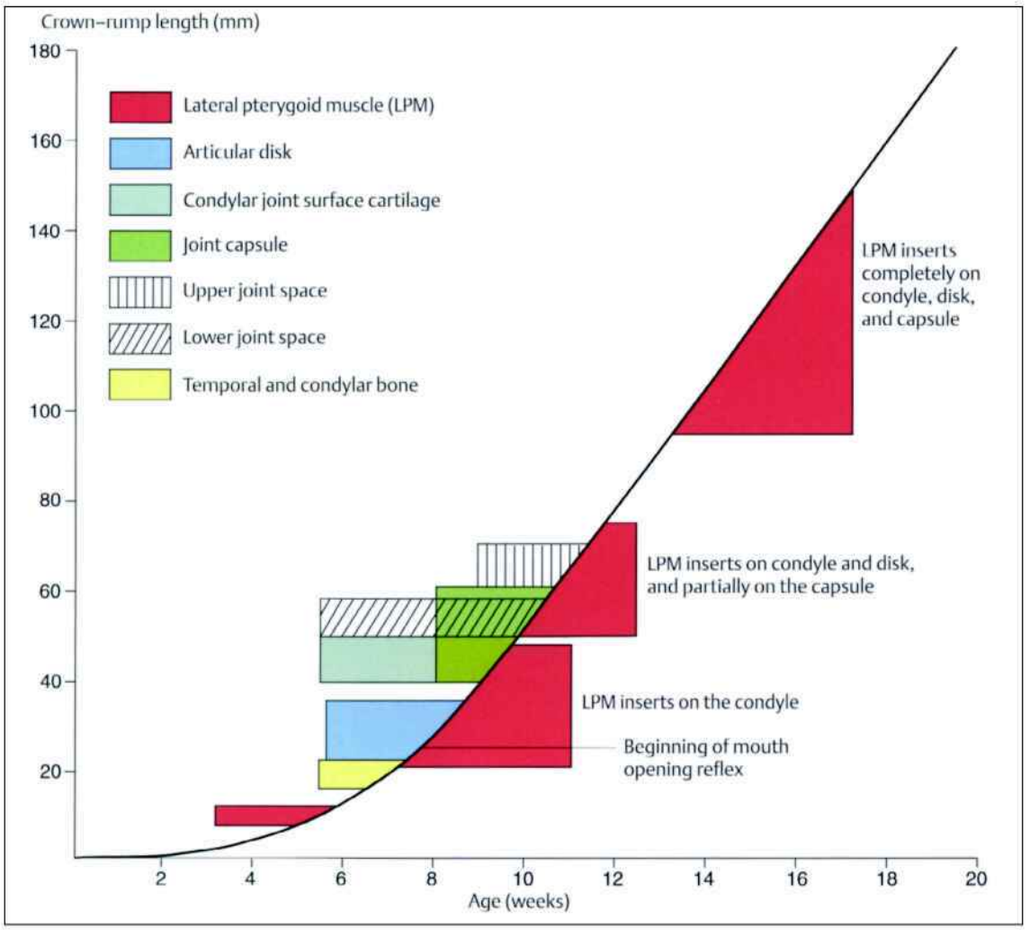
rounding bone. The fibrocartilaginous *articular disk* develops from the concentrated mesenchyme between the two joint spaces. The articular disk is not visible until the CRL is 70 mm. Even before formation of the joint spaces the disk is already thinner at its center than at the periphery and this leads to its final biconcave form (Bontschew 1996). The peripheral portions are not sharply demarcated from the surrounding loose mesenchyme. In fetuses with a CRL of 240 mm, the mesenchymal tissue changes into dense fibrous connective tissue. At this stage the peripheral region has a greater blood supply than the central region. According to Moffet (1957), compression of the disk between the temporal bone and the condyle results in an avascular central zone. At the beginning of its development the disk lies closer to the condylar process than to the future fossa. At this stage there is still a layer of loose mesenchyme between the temporal bone and the upper joint space. It is only after a CRL of 95 mm has been reached that the condylar process and the fossa become closer and the mesenchymal layer disappears.



25 Development of the lateral pterygoid muscle
Three-dimensional representation of the insertion of the lateral pterygoid muscle (1) onto a left temporomandibular joint. As the muscle develops from the eleventh week, its upper belly attaches to the condyle, capsule, and disk while its lower belly attaches only to the condyle *(2)*. At no time during development do the fibers of the lateral pterygoid muscle make direct contact with Meckel's cartilage (Ögütcen-Toller and Juniper 1994).



26 Development of the human temporomandibular joint
Graphic representation (modified from van der Linden et al. 1987) of prenatal development of the human temporomandibular joint showing its relationship to the CRL and age. First to form are the bony structures and the disk. Development of the joint capsule is accompanied by development of the upper and lower joint spaces.
It is most interesting that prenatal mandibular movements can be observed as early as weeks 7-8 (Hooker 1954, Humphrey 1968), even though most of the joint structures and even the muscle insertions do not develop until a few weeks later. It is assumed that the movements are made possible by the primary jaw joint between Meckel's cartilage and malleus-incus (Burdi 1992).

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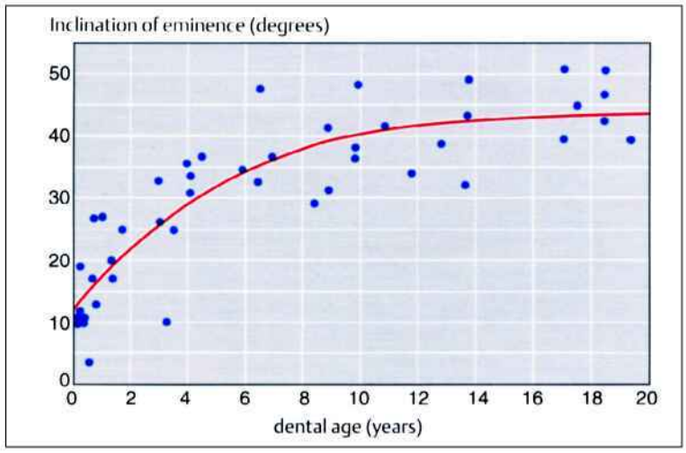
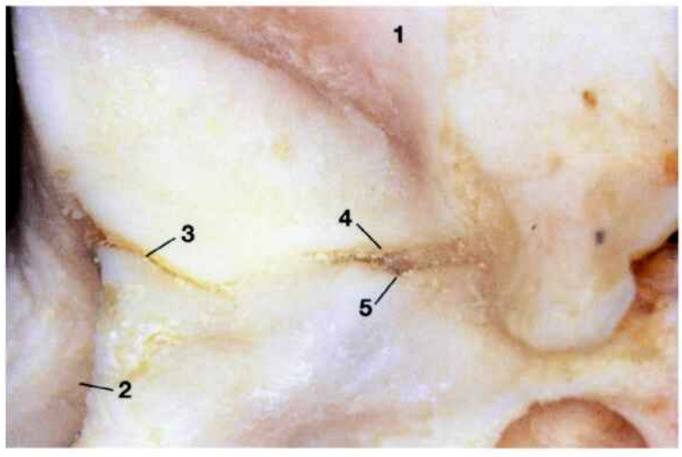
Glenoid Fossa and Articular Protuberance

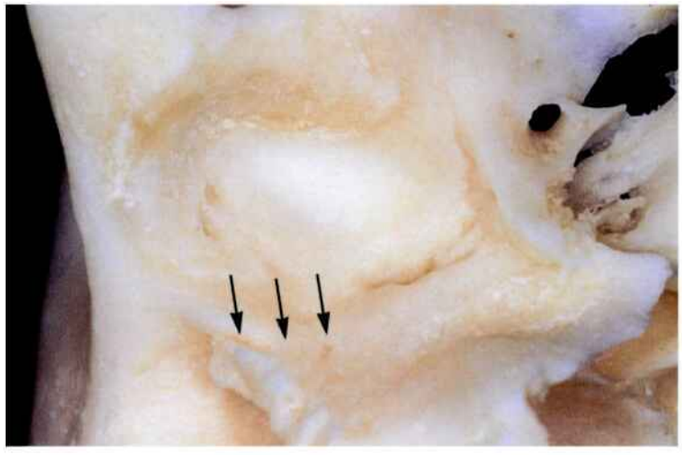
The temporal portion of the joint can be divided into four functional parts from posterior to anterior: postglenoidal process, glenoid fossa, articular protuberance, and apex of the eminence. The inclination of the protuberance to the occlusal plane varies with age and function (Kazanjian 1940), but is 90% determined at the age of 10 years (Nickel et al. 1988). Three fissures can be found at the transition to the tympanic plate of the temporal bone: the squamotympanic, petrotympanic, and petrosquamous fissures (Fig. 28). In patients with disk displacement, these fissures are frequently ossified (Bumann et al. 1991). Under physiological conditions the only parts of the temporal portion of the joint that are covered with secondary cartilage are the protuberance and the eminence (Fig. 31). Secondary cartilage is formed only when there is functional loading. Before the fourth postnatal year stimulation of the cells of the periosteum leads to the formation of secondary cartilage (Hall 1979, Thorogood 1979, Nickel et al. 1997). With no persisting functional load the chondrocytes of the condyle would differentiate into osteoblasts (Kantomaa and Hall 1991).



27 Inclination of the articular protuberance to the occlusal plane
This graph (adapted from that of Nickel et al. 1988) indicates the inclination of the posterior slope of the eminence (articular protuberance) in relation to the occlusal plane. Accordingly, at the age of 3 years the eminence has reached 50% of its final shape (Nickel et al. 1997). Between the tenth and twentieth year there is a difference of only 5°. The study material originates from the osteological collection of Hamman-Todd and Johns Hopkins, Cleveland Museum of Natural History.



28 Joint region of the temporal bone
Inferior view of the temporal portion of a defleshed temporomandibular joint. Near the upper border of the picture is the articular eminence (1) and at the far left is the external auditory meatus (2). In the posterior portion of the fossa the squamotympanic fissure (3) is found laterally, and the petrosquamous (4) and petrotympanic (5) fissures are found medially. Both the superior stratum of the bilaminar zone and the posterior portion of the joint capsule, and sometimes also the fascia of the parotid gland can insert into these fissures.



29 Ossification of the fissures and disk displacement
Inferior view of a temporal bone with partially ossified fissures. The lateral half of the squamotympanic fissure is completely ossified (arrows). The superior stratum of the bilaminar zone can now insert only into the periosteum in this region. It has been shown that these fissures are ossified in more than 95% of patients with disk displacement, whereas in joints without disk displacement normal fissure formation prevails (Bumann et al. 1991).

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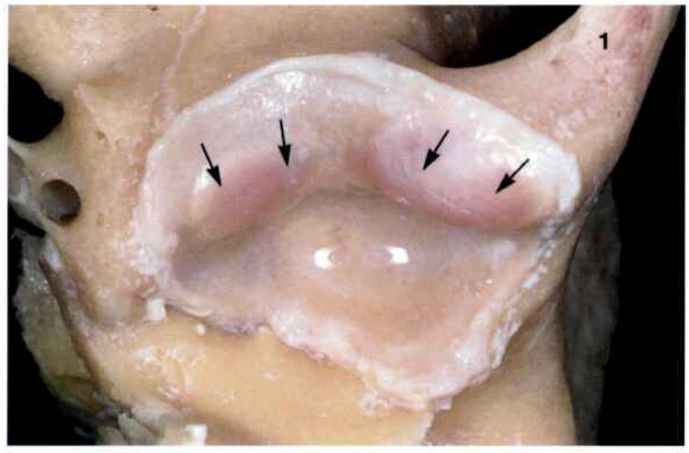
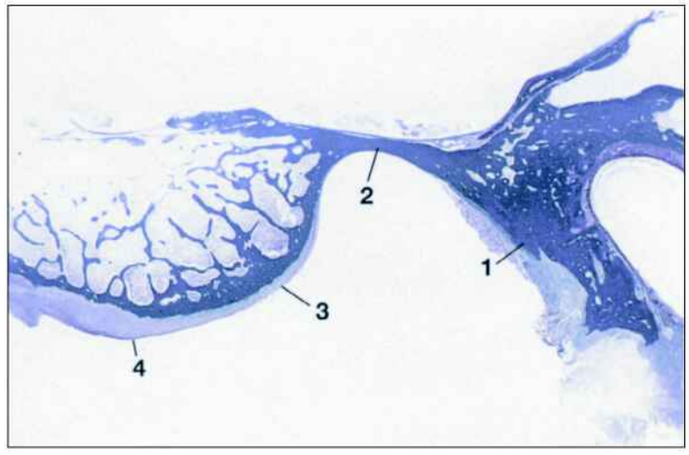
However, the maturation process of these cells is delayed by functional demands (Kantomaa and Hall 1988). Loading reduces the intracellular concentration of cyclic adenosine monophosphate (cAMP). This increases the rate of mitosis and suppresses the ossification process relative to the proliferation of cartilage (Copray et al. 1985). Furthermore, the proteoglycane content of cartilage correlates with its ability to withstand compressive loads (Mow et al. 1992).

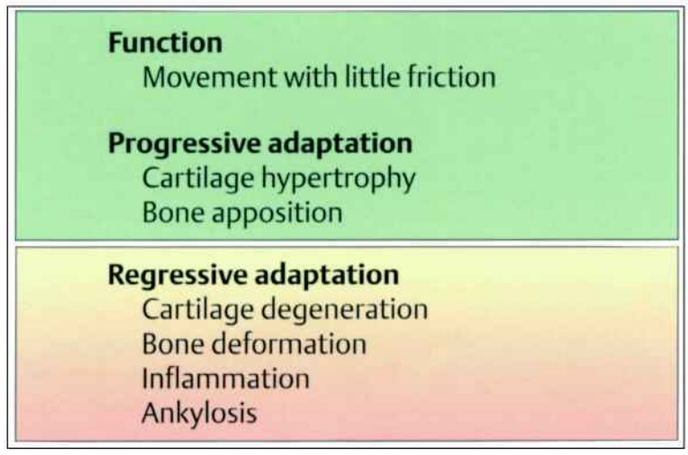
The hypothesis that structures of the temporomandibular joint are subjected to compressive loads during function has been around for many decades and is supported by a number of experimental studies (Hylander 1975, Hinton 1981, Taylor 1986, Faulkner et al. 1987, Boyd et al. 1990, Mills et al. 1994a). Studies using finite element analysis (FEA) also verify that during function, temporomandibular joint structures are subject to variable loads depending upon the individual static and dynamic occlusion (Korioth et al. 1994a, b). Different types of loads also bring about different responses in bone. When erosive changes are found in the condyle, the trabecular bone volume (TBV) of the temporal portion of the joint is significantly higher (25%) than when the condyle is unchanged (16%; Flygare et al. 1997).



30 Inferior view of the temporal cartilaginous joint surface and capsule attachment
Caudal view of the left temporomandibular joint of a newborn. The bony portions have been separated from the periosteum up to the circular insertion of the capsule and bilaminar zone. Part of the zygomatic arch (1) can be seen near the right border of the photograph. The fibrocartilaginous articular surfaces over the articular protuberance are thickened medially and laterally (arrows). When covered with synovial fluid they allow movements with virtually no friction (Smith 1982).



31 Sagittal histological section showing buildup of the temporal joint components
The temporal portion of the joint can be divided into four functional components: 1 postglenoidal process, 2 glenoid fossa, 3 articular protuberance, and 4 apex of the eminence. As a rule, no cartilage can be identified within the fossa. The average thickness of the fibrous cartilage over the protuberance and the eminence is between 0.07 and 0.5 mm (Hansson et al. 1977). As this photograph shows, there can be considerable variation in thickness within the same individual.



32 Function and structural adaptation of the articular eminence
A summary of the basic anatomical changes in the temporal joint tissues. Increased functional loading will cause hypertrophy through secondary cartilage formation and bone deposition (progressive adaptation). Persistent nonphysiological loading (massive influences) leads to deforming or degenerative changes. This regressive adaptation is accompanied by more or less noticeable rubbing sounds, sometimes in combination with pain.

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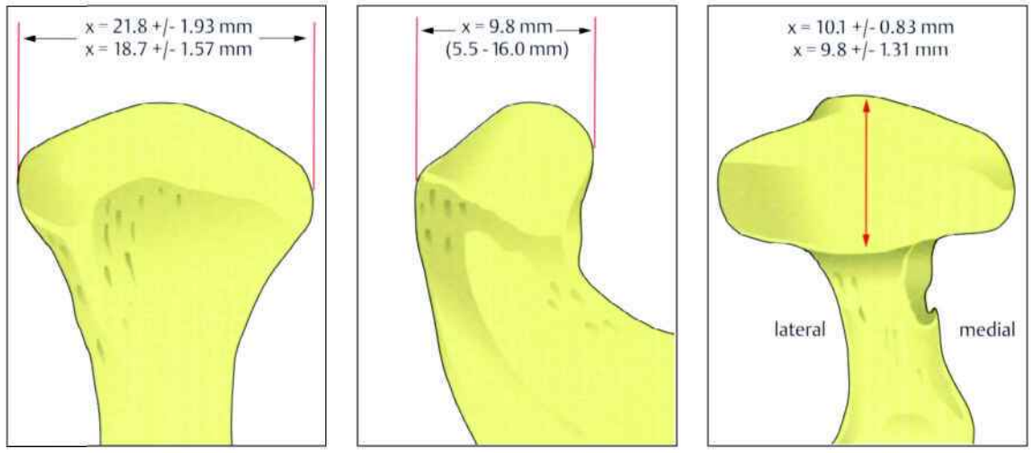
Mandibular Condyle

Human condyles differ greatly in their shapes and dimensions (Solberg et al. 1985, Scapino 1997). From the time of birth to adulthood the medial-lateral dimension of the condyle increases by a factor of 2 to 2.5, while the dimension in the sagittal plane increases only slightly (Nickel et al. 1997). The condyle is markedly more convex in the sagittal plane than in the frontal plane.

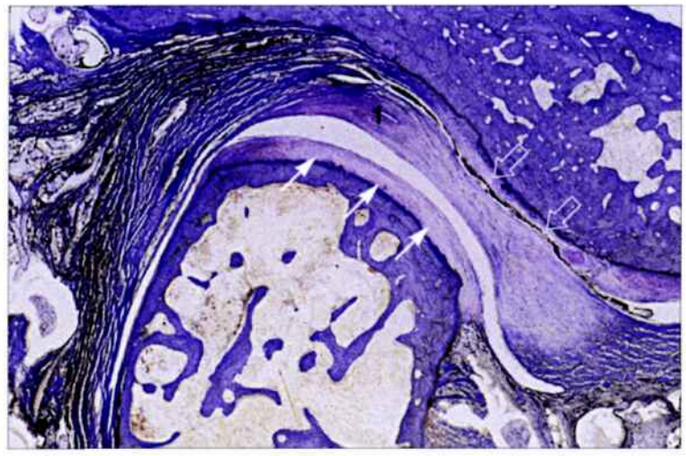
The articulating surfaces of the joint are covered by a dense connective tissue that contains varying amounts of chondrocytes, proteoglycans, elastic fibers and oxytalan fibers (Hansson et al. 1977, Helmy et al. 1984, Dijkgraaf et al. 1995). The composition and geometric arrangement of the extracellular matrix proteins within the fibrous cartilage determine its properties (Mills et al. 1994 a,b). Cartilage that can absorb and distribute compressive loads is characterized by a matrix with high water content and high molecular weight chondroitin sulfate in a network of type II collagen (Maroudas 1972, Mow et al. 1992). A low level of functional demand upon the joint leads to an increase of type I collagen and a reduction of type II (Pirttiniemi et al. 1996). Interleukin la inhibits the matrix synthesis of chondrocytes,



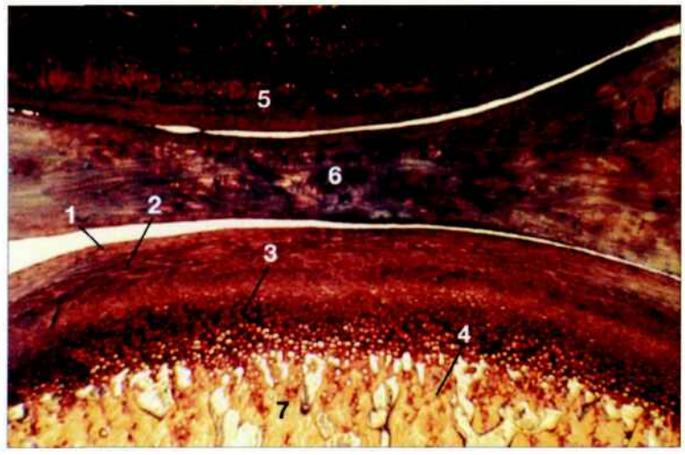
33 Condyle dimensions
Left: Width of condyle in the frontal plane (Solberg et al. 1985). The average condylar width is significantly greater in men (21.8 mm) than in women (18.7 mm).

Center: Anteroposterior dimension of the central portion shown in the sagittal plane (Öberg et al. 1971; minimum and maximum in parentheses).

Right: Anteroposterior dimension of the condyle in the horizontal plane. There is no significant difference between men (10.1 mm) and women (9.8 mm).



34 Functional joint surface
Histological preparation showing a physiological fibrocartilaginous joint surface (thin arrows) of the condyle of a 58-year-old individual. In spite of the intact joint surface on the condyle, the pars posterior (1) of the disk is flattened and the functional fibrocartilaginous temporal surface of the joint on the articular protuberance shows degenerative changes (outlined arrows). The subchondral cartilage has not yet been affected and would appear intact on a radiograph.



35 Buildup of the condylar cartilage
Histologically, the secondary cartilage of the condyle is made up of four layers:

1 Fibrous connective-tissue zone
2 Proliferation zone with undifferentiated connective-tissue cells
3 Fibrous cartilage zone
4 Enchondral ossification zone

Other structures shown are:
5 Eminence
6 Disk
7 Condyle

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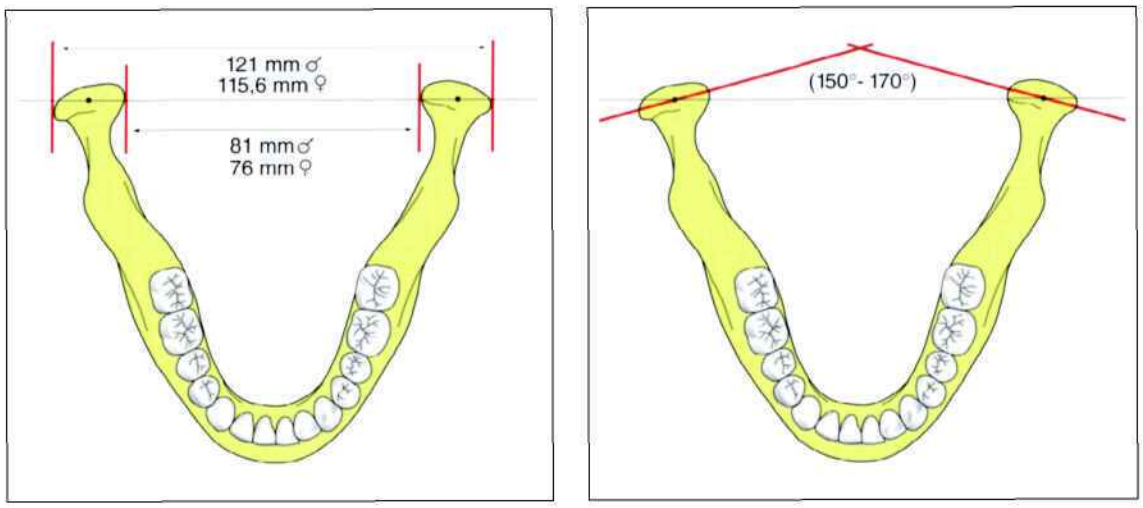
while the transforming growth factor TGF-b promotes it (Blumenfeld et al. 1997). The collagen fibers of the fibrocartilaginous joint surfaces are oriented mainly in a sagittal plane (Steinhardt 1934).

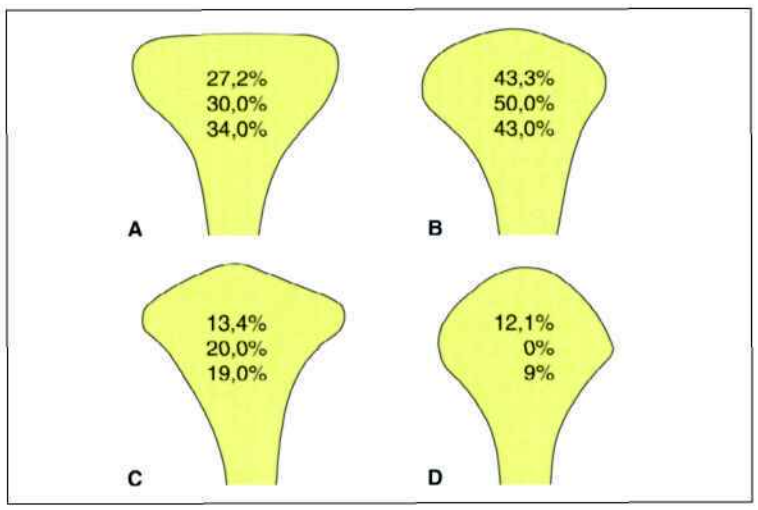
Joint surface cartilage must permit frictionless sliding of the articulating structures while at the same time it must be able to transmit compressive forces uniformly to the subchondral bone (Radin and Paul 1971). Hypomobility of the mandible results in a more concentrated loading of the joint surfaces. Even if the forces in the masticatory system remain the same, the load per unit of area on the cartilage will be increased when there is hypomobility. The amount of structural change depends upon the amplitude, frequency, duration, and direction of the loads (Karaharju-Suvanto et al. 1996).

In joints that have undergone erosive changes, the percentage of trabecular bone volume (21%) and the total bone volume (54%) are significantly higher than the corresponding 15% and 40% found in condyles without these changes (Flygare et al. 1997). Degenerative changes therefore are closely associated with nonphysiological loading of the joint surfaces.

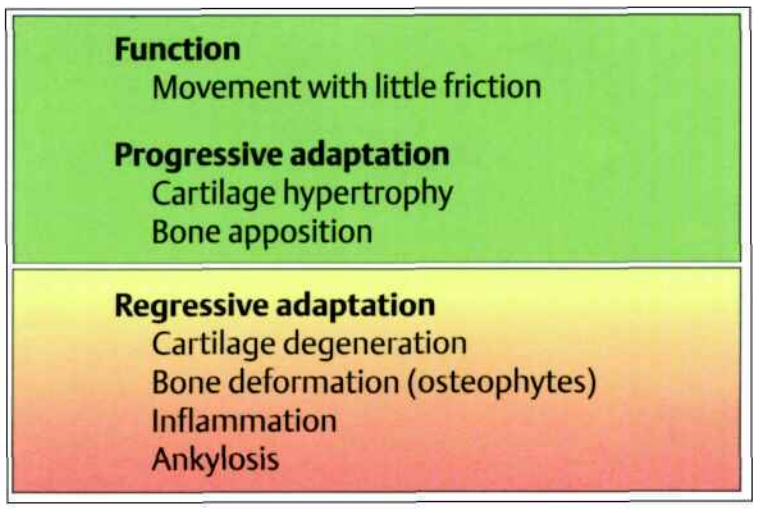


36 Intercondylar distance
Left: Sex-specific data on the distances between pairs of medial poles and lateral poles of the condyle (after Christiansen et al. 1987). The numbers given are average values. A difference of 5-10 mm in the intercondylar distance will have a corresponding effect on the tracings of condylar movements and the accuracy of simulated movements in the articulator (see pp. 216 and 243).

Right: Schematic drawing illustrating the intercondylar angle.



37 Condylar shapes in the frontal plane
According to Yale et al. (1963) 97.1 % of all condyles fall into one of four groups based upon their frontal profile. These are described as either flat (A), convex (B), angled (C), or round (D). The relative frequencies of occurrence are taken from the works of Yale et al. (1963), Solberg et al. (1985), and Christiansen et al. (1987). The condyle form affects the radiographic image of this part of the joint in the Schüller projection (Bumann et al. 1999) and the loading of the joint surfaces (Nickel and McLachlan 1994).



38 Function and structural adaptation of the condyle
Summary of the basic anatomical and functional changes in the condylar portion of the joint. Increased functional loading will stimulate cartilaginous hypertrophy (= progressive adaptation) that is not noticeable clinically. Continuous nonphysiological loading of the condyle can lead to degeneration, deformation, and even ankylosis (Dibbets 1977, Stegenga 1991). These changes may be accompanied by pain or, with sufficient adaptation, they may progress painlessly.

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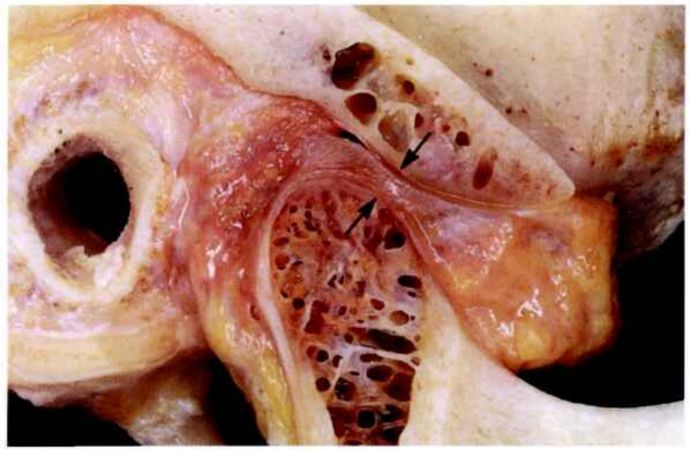
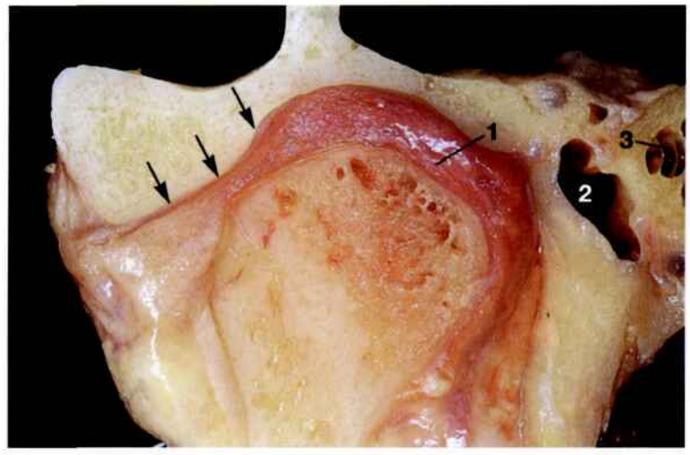
Positional Relationships of the Bony Structures

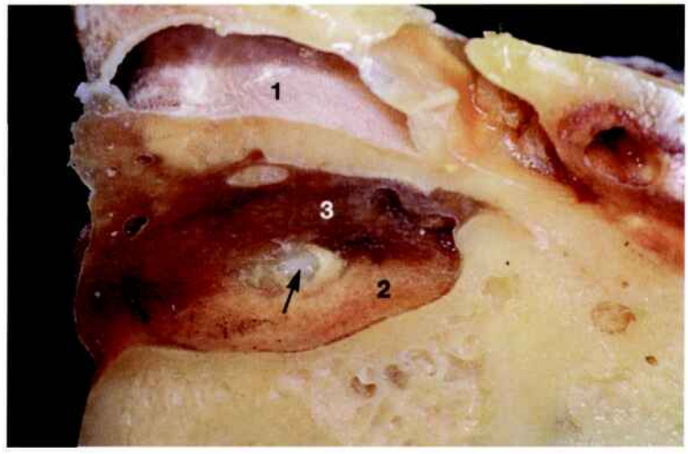
The position of the condyle relative to the articular protuberance has been a subject of controversy in dentistry for many years (Lindblom 1936, Pullinger et al. 1985). A well-defined condylar position oriented to the maximal occlusion is especially relevant to extensive dental treatment (Spear 1997). In the past, to transfer the jaw relations to an articulator the condyles were always placed in their most posterosuperior position because this relationship could be most easily reproduced (Celenza and Nasedkin 1979). Under purely static conditions the condylar position is dependent upon the shape of the fossa, the inclination of the protuberance, and the shape of the condyle. In the 1970s this led to the assignment of a geometric centric position of the condyle in the fossa (Gerber 1971). However, the dimensions of the joint space are quite variable in both the sagittal plane (anterior, posterior, and superior) and the transverse plane (medial, central, and lateral) (Pullinger et al. 1985, Hatcher et al. 1986, Christiansen et al. 1987, Bumann et al. 1997). For this reason the concept of an anatomical orientation is untenable, and the radiographic techniques



39 Sagittal relationships
Macroscopic anatomical preparation showing the relation of the fossa, disk, and condyle to one another in the sagittal plane. Because the shapes of fossae and condyles vary so greatly, it is not possible to determine a universally applicable measurement of the condylar position. Although the physiological (i.e. centric) condylar position is defined as the most anterosuperior position with no lateral displacement (arrows), this position depends upon the basic neuromuscular tonus.



40 Frontal relationships
Macroscopic anatomical preparation showing the relation of the fossa, disk, and condyle to one another in the frontal plane. In this plane, too, there is no standard geometric arrangement of condyle and fossa because of the variability of the hard and soft tissues (Yung et al. 1990). In this preparation the disk (arrows) is displaced laterally. Structures or the bilaminar zone (1) can be identified in the medial portion of the joint. The close proximity of the joint to the middle (2) and inner ear (3) can also be observed.



41 Horizontal relationships
A right temporomandibular joint viewed from above showing the relation of the fossa, disk, and condyle to one another in the horizontal plane. The lateral portion of the joint is near the left border of the picture. Near the upper border a section through the external auditory meatus can be seen (1). The roof of the fossa has been removed. Near the center of the picture lies the transition from the pars posterior (2) to the bilaminar zone (3). The central perforation was created during sectioning, and through it can be seen the upper surface of the condyle (arrow).

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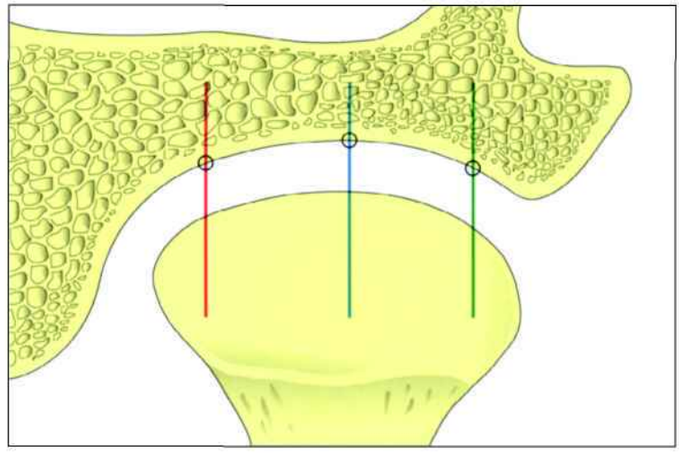
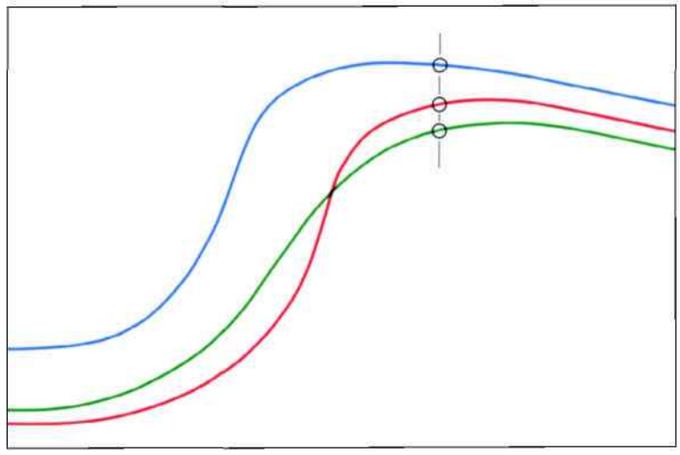
(p. 148) are unsuitable for determining a therapeutic condylar position (Pullinger and Hollender 1985). Therefore the current definitions of centric relation are geared more toward the functional conditions (van Blarcom 1994, Dawson 1995, Lotzmann 1999). It has been demonstrated experimentally that the surfaces of the temporomandibular joint are subjected to loads of 5-20 N (Hylanderl979, Brehnan et al. 1981, Christensen et al. 1986). In a patient's habitual occlusion this force is partially intercepted by the occluding premolars and molars. Tooth loss can lead to higher joint loading and regressive adaptation (van den Hemel 1983, Christensen et al. 1986, Seligman and Pullinger 1991). However, if the joint's capacity for adaptation is sufficiently great, degenerative changes may be avoided (Helkimo 1976, Kirveskari and Alanen 1985, Roberts et al. 1987). The direction of functional loading is anterosuperior against the articular protuberance (Dauber 1987). Clear evidence for this is the presence of the load-induced secondary cartilage on the joint surfaces in this region.

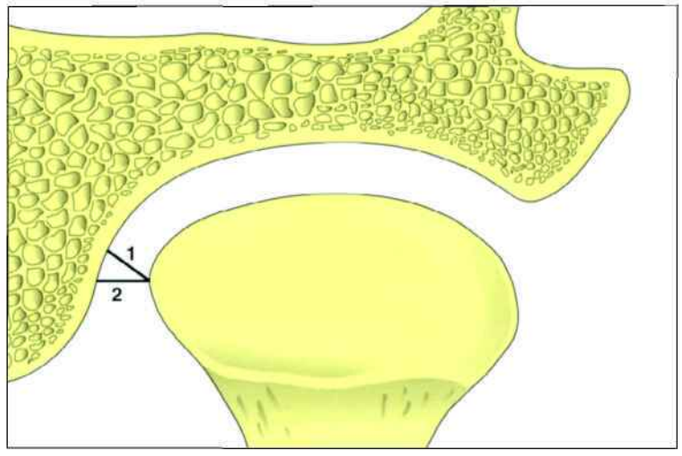
Positioning of the condyles on the protuberances is accomplished exclusively through the antagonistic activity of the neuromuscular system and from a functional standpoint requires no border position.



42 Relationships in the frontal plane
Schematic depiction of the joint space relationships in the frontal plane. A number of studies have reported that the dimensions found in the lateral, central, and medial parts may vary greatly (Christiansen et al. 1987, Vargas 1997). Although the lateral portion is affected more frequently by degenerative changes, the width of the joint space is usually least at its center (blue line).



43 Contours on the temporal surface of the joint
Schematic drawing (modified from Hasso et al. 1989) of the contours in the lateral (green), central (blue), and medial (red) regions of the joint. The entire protrusive functional path is represented as a convex bulge that can vary markedly as the result of regressive or progressive adaptation. Therefore, the loads borne by the lateral and medial portions of the joint during function are also influenced by the morphology of the articular protuberance (Öberg et al. 1971, Hylander 1979, Hinton 1981).



44 Relationships in the medial part of the joint
Schematic drawing (modified from Christiansen et al. 1987) of the positional relationships in the medial portion of a left temporomandibular joint. This finding also emphasizes the fundamental principles of physiological joint movements. As with all other joints, the temporomandibular joint has a passive "play" space in all directions and is thus not confined to any border position.
Average values: 1 = 3.4 mm; 2 = 4.4 mm

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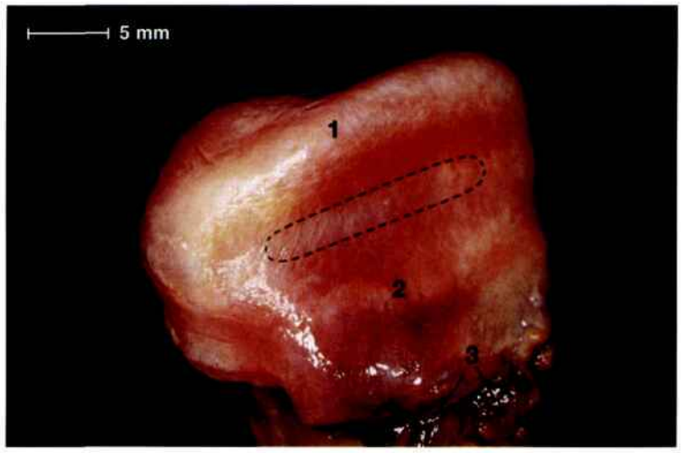
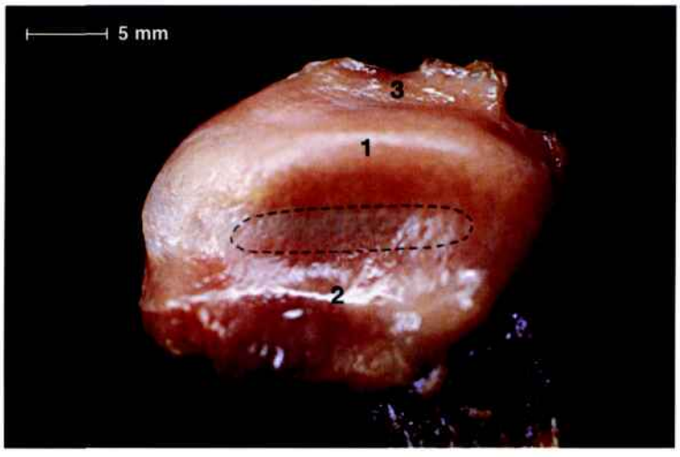
Articular Disk

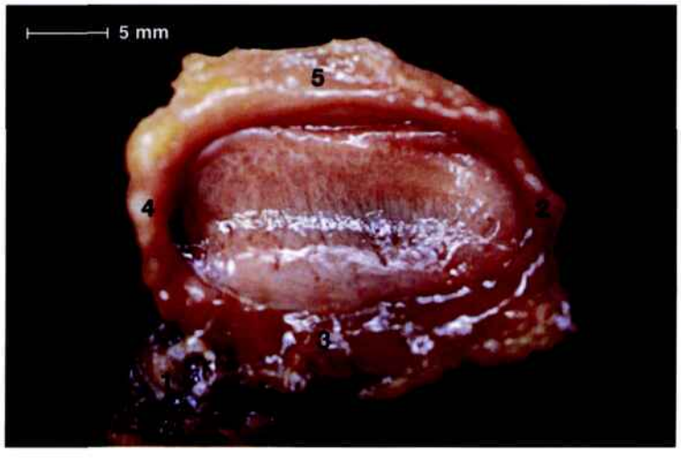
The articular disk can be divided into three regions based upon their function: the partes anterior, intermedia, and posterior. The primary functions of the disk are to reduce sliding friction and to dampen load spikes (McDonald 1989, Scapino et al. 1996). The extracellular matrix of the fibrocartilaginous disk consists primarily of type I and type II collagen (Mills et al. 1994b). The orientation of the collagen fibers in the disk displays a typical pattern (Knox 1967, Scapino 1983). In the pars intermedia dense bundles of collagen fibers run approximately in a sagittal direction. These intertwine with the exclusively transverse fibers of the pars anterior and pars posterior (Takisawa et al. 1982). Elastic fibers are found in all parts of the disk (Nagy and Daniel 1991) but are more numerous in the pars anterior and in the medial portion of the joint (Luder and Babst 1991). A reduction in the thickness of the disk results in an exponential increase in the load it experiences (Nickel and McLachlan 1994). The more rapidly a load is applied, the "stiffer" the disk reacts (Chin et al. 1996). The inferior stratum and the convexity of the pars posterior help stabilize the disk on the condyle.



45 Alignment of fibers within the disk and their attachment to the condyle
Macroscopic anatomical preparation of the disk-condyle complex of a right temporomandibular joint. The collagen fibers of the pars posterior (1) and the pars anterior (2) run from the medial to the lateral pole of the condyle (Moffet 1984), making possible a wide range of movement of the disk relative to the condyle in the sagittal plane. The fibers of the pars intermedia (outlined area), on the other hand, run in a more sagittal direction. The medial pterygoid muscle (3) makes its insertion at the anteromedial region.



46 Cranial view
A view from above of the disk in Figure 45 after removal of the condyle. In this view the transverse course of the fibers in the pars posterior (1) and pars anterior (2) can be seen more clearly. Histologically the disk is composed of dense collagenous connective tissue with a few embedded chondrocytes (Rees 1954). In the pars anterior and pars posterior the chondrocytes are found in clusters, but in the pars intermedia (outlined) they are arranged uniformly. Part of the bilaminar zone (3) can be seen attached at the distal border of the pars posterior.



47 Inferior view of the same disk
In this view the insertion of a portion of the superior head of the lateral pterygoid muscle (1) can be clearly seen. The remaining fibers of the superior head insert on the condyle. This preparation also demonstrates the insertion of the lateral (2), anterior (3), and medial (4) borders of the joint capsule. In the posterior part of the joint the capsule is connected to the posterior surface of the condyle by the stratum inferium (5) of the bilaminar zone (see p. 47).

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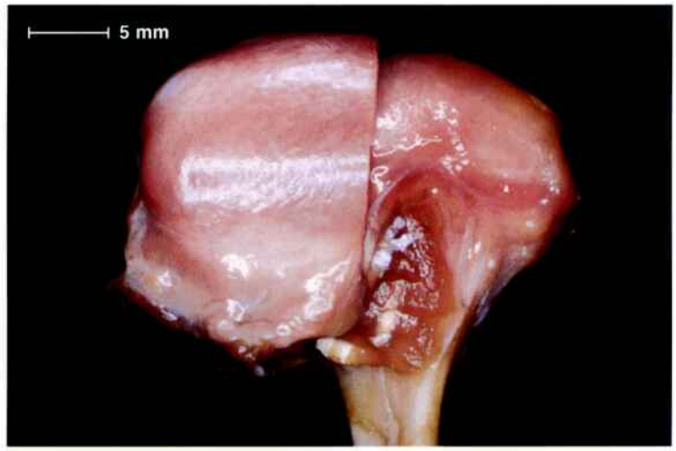
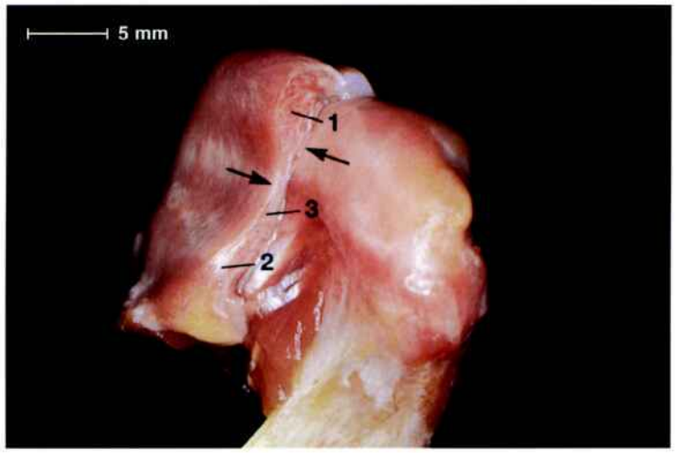
Anatomical Disk Position

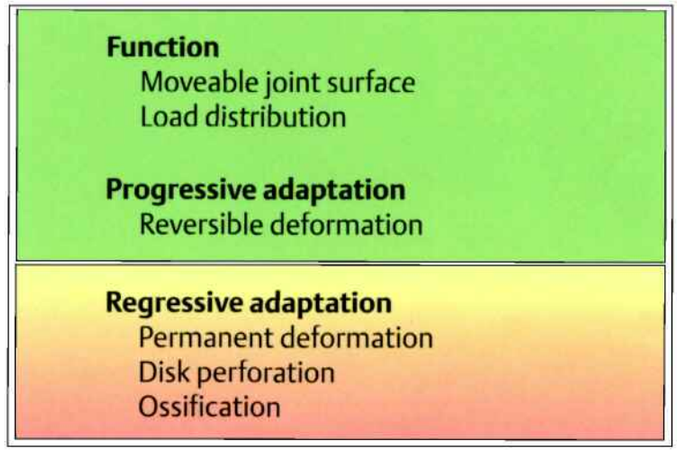
In a physiological temporomandibular joint, the pars posterior of the disk lies on the superior portion of the condyle. In the "centric condylar position" the thinnest part of the disk, the pars intermedia, is located between the anterosuperior convexity of the condyle and the articular protuberance (van Blarcom 1994). This finding is also supported by studies using measurements and mathematical models (Bumann et al. 1997, Kubein-Meesenburg 1985). The pars anterior lies in front of the condyle (Steinhardt 1934, Wright and Moffet 1974, Scapino 1983). The disk is attached to the medial and lateral poles of the condyle by means of the transversely aligned collagen fibers of the pars anterior and pars posterior. Viewed by itself, this anatomical arrangement with the condyle allows a great degree of movement during active mandibular movements (see p. 46). The disk exhibits viscoelastic properties under compressive loads. Its resistance is strengthened by the arrangement of the collagen fibers (Shengyi and Xu 1991). The elastic fibers within the disk serve primarily to restore the shape of the disk after a load has been removed (Christensen 1975).



48 Anterosuperior aspect of the disk-condyle complex
Macroscopic anatomical preparation of a left temporomandibular joint showing the relationship between disk and condyle. The lateral half of the disk has been removed for a clearer view. The dorsal border of the pars posterior is near the region of the apex of the condyle. From a functional point of view, this broad description is not very helpful for diagnostic purposes because the physiological position of the pars posterior depends to a large extent upon the inclination of the protuberance.



49 Anterolateral aspect of the disk-condyle complex
The same preparation in half profile. Here the pars posterior (1), pars intermedia (3), and pars anterior (2) can be clearly distinguished. Although the posterior border of the pars posterior lies over the apex of the condyle, the pars intermedia is in front of the anterosuperior convexity (arrows) of the condyle. The pars anterior is 2.0 mm thick, the pars intermedia 1.0 mm thick, and the pars posterior 2.7 mm thick (Gaa 1988).



50 Function and structural adaptation of the disk
Functionally, the disk serves as a "moveable fossa" for the condyle. Because of its unique tissue structure it can cushion and dampen peaks of force. Progressive adaptation differs from regressive in that the former is reversible. Strictly speaking, there is no "positive" tissue reaction in the disk because functional loads as well as continuous nonphysiological loads result in deformation.

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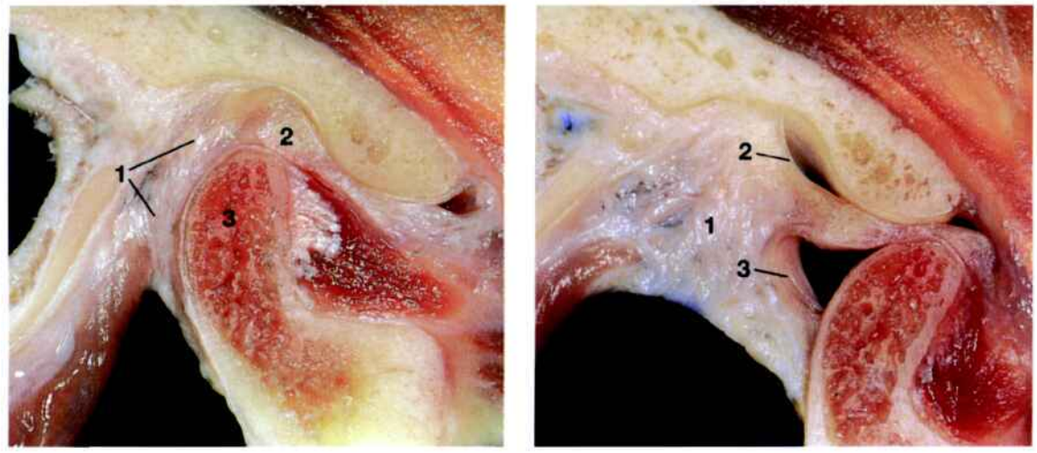
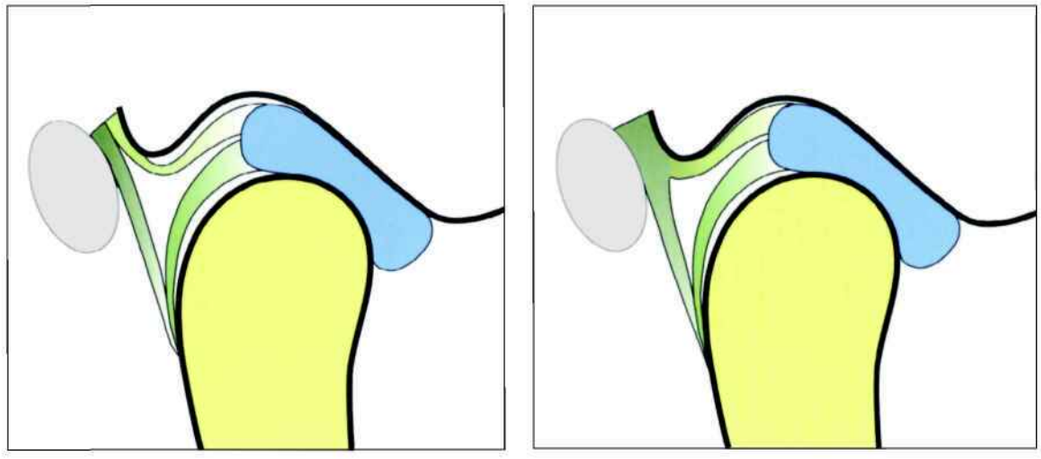
Bilaminar Zone

The posterior portion of the temporomandibular joint has been variously referred to as the bilaminar zone (Rees 1954), retroarticular plastic pad (Zenker 1956), retroarticular pad (DuBrul 1988), retrodiskal fat pad (Murikami and Hoshino 1982), or trilaminar zone (Smeele 1988). It consists of an upper layer (superior stratum) and a lower layer (inferior stratum) (Rees 1954, Griffin and Sharpe 1962). Between these two layers lies the genu vasculosum with its numerous vessels, nerves, and fat cells (Griffin and Sharpe 1962). The *superior stratum* is composed of a loose network of elastic and collagen fibers, fat, and blood vessels (Zenker 1956). By contrast, the *inferior stratum* is made up of tight collagen fibers (Rees 1954, Wilkes 1978, Luder and Bobst 1991). In the bilaminar zone the collagen fibers are more loosely organized and run more or less in the sagittal plane (Mills et al. 1994b). The fibers of both strata stream into the pars posterior of the disk and there intertwine with the transverse fibers of the pars posterior and the sagittal fibers of the pars intermedia (Scapino 1983). The elastic fibers in the bilaminar zone have larger diameters than those of the disk and are concentrated predominantly in the superior stratum (Rees 1954, Scapino 1983, Mills et al. 1994a).

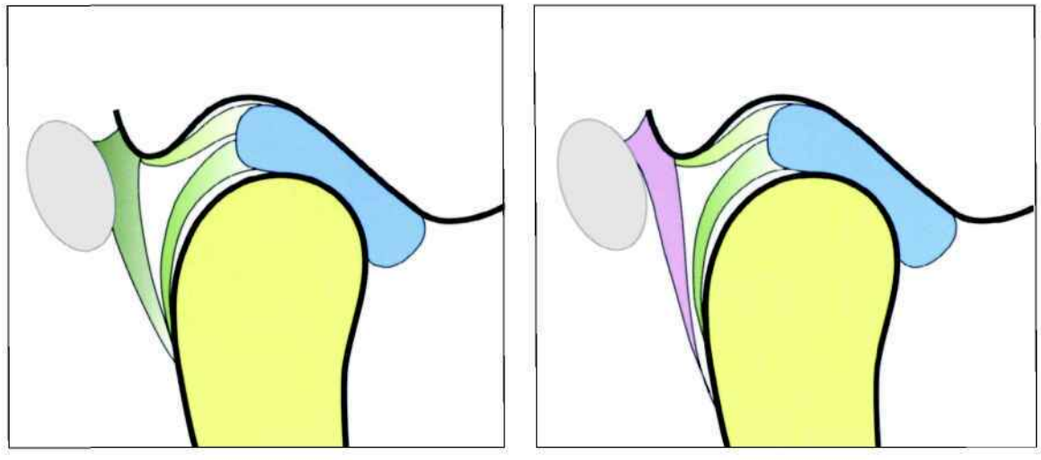


51 Macroscopic anatomical preparation
Left: With the jaws closed the bilaminar zone (1) fills the space posterior to both the pars posterior (2) and the condyle (3). The inferior stratum stabilizes the disk on the condyle in the sagittal plane. An overextension of the bilaminar zone through posterosuperior displacement of the condyle is an essential precondition for an anterior disk displacement to occur.
Right: With the mouth open the genu vasculosum (1) fills with blood. The superior stratum (2) and inferior stratum (3) can be easily identified.



52 Variants of the posterosuperior attachment
Left: Type A insertion. The superior stratum and the posterior joint capsule run separately to their insertions in the fissures. This type of insertion occurs most often in the medial portion of the joint.

Right: Type B insertion. Here the superior stratum and the posterior joint capsule merge before reaching the fissures and continue posterosuperiorly as one uniform, undifferentiated structure. This variant is the second most common in the medial portion of the joint.



53 Variants of the posterosuperior attachment
Left: Type C insertion. The superior stratum inserts on the glenoid process because the fissures are completely filled by the posterior portion of the joint capsule. This type of insertion is found most frequently in the lateral part of the joint.

Right: Type D insertion. In this rare variant no posterior capsule structure can be demonstrated histologically. The posterior boundary is formed by the parotid fascia.

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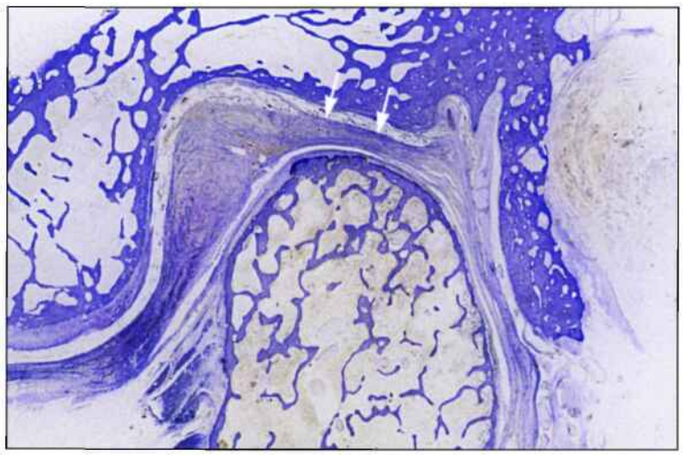
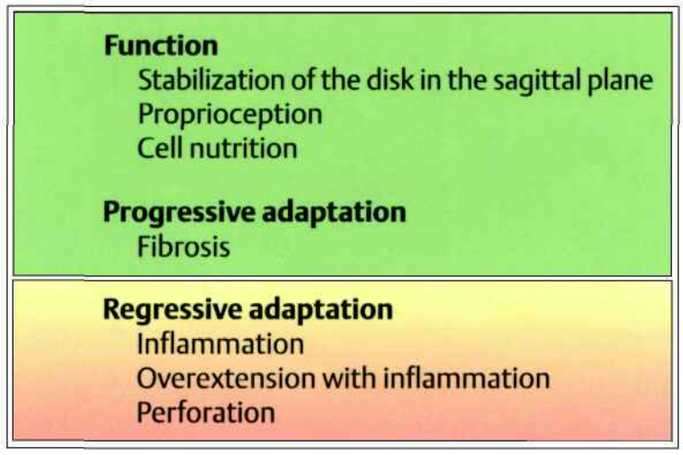
The superior stratum is attached posteriorly to the bony auditory meatus, the cartilaginous part of the auditory meatus, and the fascia of the parotid gland (Scapino 1983). Four insertion variations can be distinguished (Bumann et al. 1999).

The inferior stratum inserts on the posterior side of the condyle below the fibrocartilaginous articulating surface and is responsible for stabilizing the disk on the condyle. Anterior disk displacement is possible only when the predominantly collagenous inferior stratum becomes overstretched. The superior stratum, on the other hand, is responsible for retracting the articular disk, especially during the initial phase of closure, but is of lesser importance in the occurrence of anterior disk displacement (Eriksson et al. 1992). These facts are very important to consider in the diagnosis and treatment of disk displacements. Continuous posterior or posterosuperior loading of the bilaminar zone eventually leads to fibrosis and sometimes to the formation of a pseudodisk (Hall et al. 1984, Isbergetal. 1986, Kurita et al. 1989, Westesson and Paesani 1993, Bjornland and Refsum 1994).

54 Histology of the bilaminar zone
The superior stratum (1), genu vasculosum (2), and inferior stratum (3) can be clearly distinguished from one another. Sensory and sympathetic nerve fibers provide pain perception and regulation of blood-vessel tonus. Here the neuropeptides A and Y effect vasoconstriction (Lundberg et al. 1990, Grundemar and Hakanson 1993) while vasodilation is brought about by the vasoactive intestinal peptide, the peptide histidine-isoleucine amide and acetylcholine (Widdicombe1991).



55 Progressive adaptation (fibrosis)
Chronic overloading brings about fibrosis (arrows) and reduction of the number of blood vessels. Such fibrosis can be seen in 64-90% of patients, depending on the position of the disk. Posterior and posterosuperior condylar displacement without adaptation of the bilaminar zone is a common cause of joint pains. Therefore, previous adaptation of the bilaminar zone can be considered a favorable factor for treatment.



56 Function and structural adaptation of the bilaminar zone
In addition to supplying nutrients and proprioception, the inferior stratum is of special importance in stabilizing the disk in the sagittal plane. Increased functional loading can lead to its fibrosing. Our own studies indicate that in spite of mechanical loading, fibrosis does not occur in 10-36% of joints. Chronic nonphysiological overloading usually results in perforation, overextenion, or inflammation.

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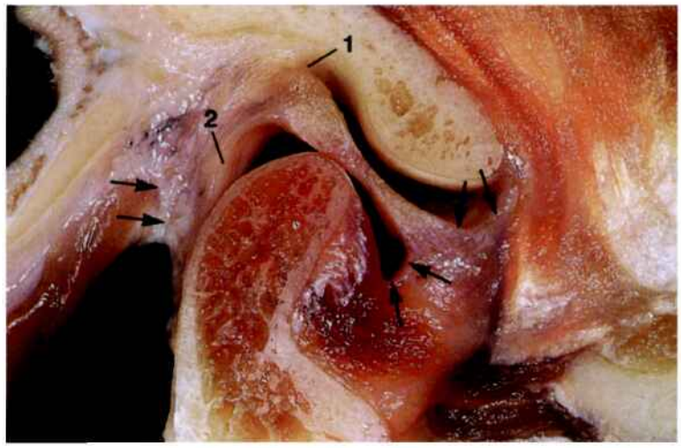
Joint Capsule

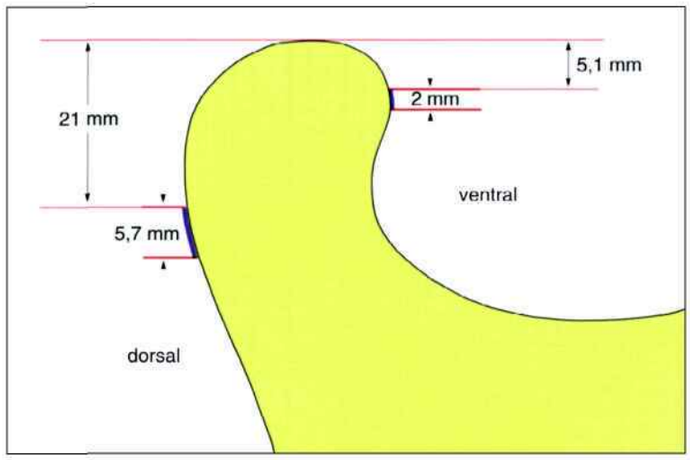
The bony parts of the temporomandibular joint are enclosed in a thin fibrous capsule. In addition to lateral, medial, and posterior capsule walls, there is an anterior wall that can be divided into upper and lower portions. The medial and lateral walls are reinforced by the similarly named medial and lateral ligaments (Schmolke 1994, Loughner et al. 1997). Attachment of the disk to the lateral and medial poles of the condyle is independent of the capsular structure (Fig. 60). The boundaries of the superior attachment of the capsule to the temporal bone are shown in Figure 30.

Because of its loose connective-tissue structure the anterior capsule wall cannot withstand as much loading as the other parts of the capsule (Koritzer et al. 1992, Johannson and Isberg 1991). The insertion of the capsule on the condyle is superficial and it lies at different levels on different sides of the condyle (Figs. 58, 61). Anterior disk displacements are accompanied not only by overextension of the inferior stratum, but also by stretching of the lower anterior capsule wall (Scapino 1983). The amount of extension is directly related to the amount of anterior disk displacement (Katzberg et al. 1980).

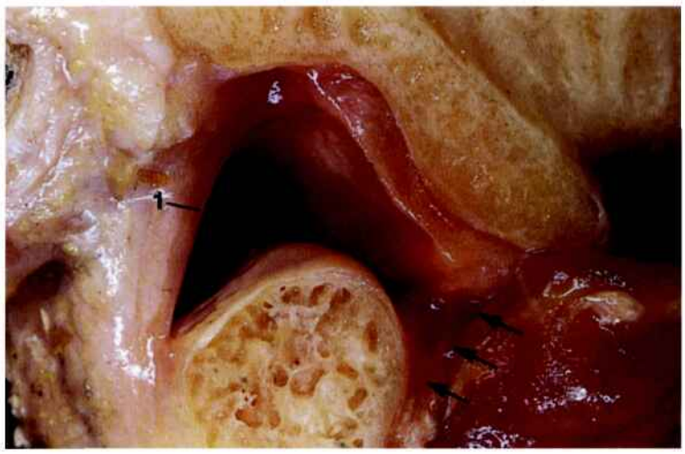
57 Joint capsule in the sagittal plane
By applying artificial traction on the specimen, the anterior portions of the upper and lower joint capsules (arrows) have been made more clearly visible. Posteriorly the joint spaces are bounded by the superior stratum (1) and inferior stratum (2). The posterior capsule wall lies behind the genu vasculosum. The type-III receptors of the capsule are only activated by heavy tensile loads on the lateral ligament and serve then to stimulate the elevator muscles (Kraus 1994).



58 Attachment of the capsule to the condyle
Schematic representation of the attachment of the joint capsule in the sagittal plane. The band-like insertion is significantly broader posteriorly than anteriorly. Because of the insertion of the lateral pterygoid muscle on the anterior surface of the condyle, the anterior part of the joint capsule attaches much higher anteriorly than posteriorly. The values given are based on measurements made on 39 human temporomandibular joints (Brauckmann 1995).



59 Overdistended capsule
Anterior disk displacement requires not only a stretching of the inferior stratum (1), but also a distention of the lower anterior wall of the joint capsule (arrows). However, because the connective tissue of the anterior capsule wall is much looser, disk displacement depends almost exclusively on posterior loading vectors and the adaptability of the inferior stratum. A downward movement of the condyle as shown here without downward movement of the disk is possible only with extensive stretching of the inferior stratum.



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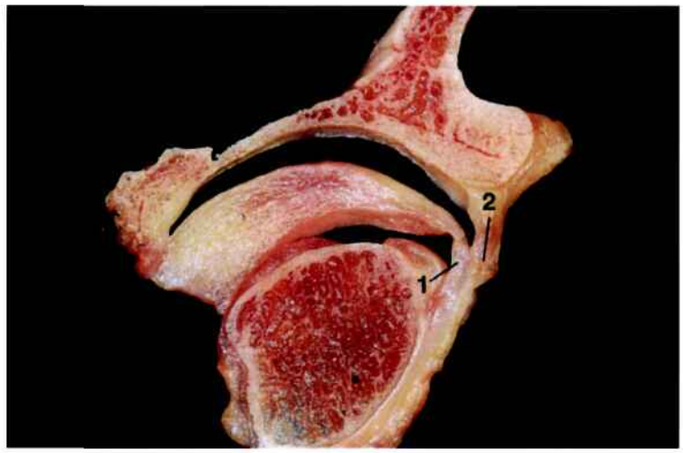
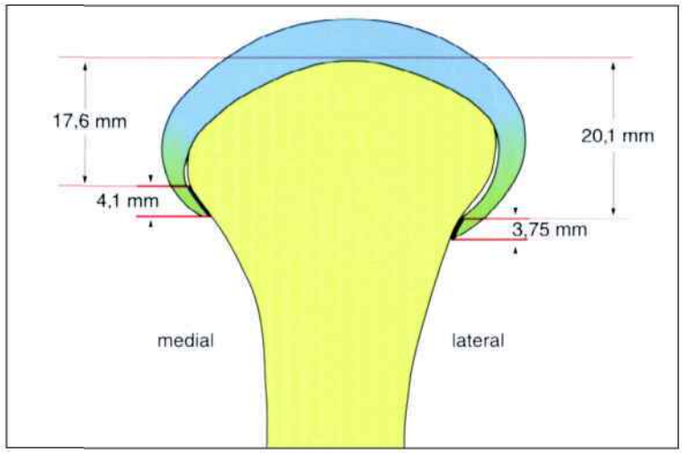
The interior surface of the capsule is covered by synovial membrane (Dijkgraaf et al. 1996a, b). The synovial cells form synovial fluid which serves to bring nutrients to the avascular cartilage of the joint surfaces and to reduce friction. Lubrication of the joint surfaces is accomplished through two mechanisms (Okeson 1998). One is the displacement of synovial fluid from one area to another by jaw movements. The other is the ability of the cartilage to store a limited amount of synovial fluid. Under functional pressure the fluid is again released to ensure minimal friction within the joint, in spite of static and dynamic loads (Shengyi and Xu 1991).

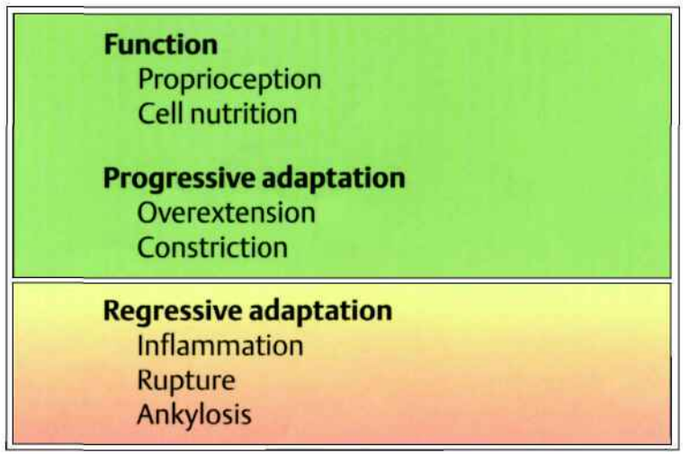
A second important function of the joint capsule is proprioception. Receptors are divided into four types (Wyke 1972, Clark and Wyke 1974, Zimny 1988). Type I have a low threshold, adapt slowly, provide postural information, and have a reflexive inhibiting effect on the antagonistic muscles. Likewise, type II have a low threshold but adapt quickly and provide information about movements. Type III have a high threshold and are slow to adapt. Type IV receptors stand ready for sensory pain perception and do not "fire" under normal conditions.



60 Disk and capule attachments in the frontal plane
Macroscopic anatomical preparation of a temporomandibular joint in the frontal plane. Although the insertion of the disk on the condyle at the condylar poles has been described by some as an attachment through the joint capsule in the form of a "diskocapsular system" (Dauber 1987), other studies (Solberg et al, 1985, Bermejo et al. 1992) identify two separate connective-tissue structures for attachment to the condyle, one for the disk (1) and the other for the capsule (2).



61 Attachment of the joint capsule to the condyle
Schematic representation of the capsule attachment in the frontal plane. The collagen fibers of the disk and capsule insert somewhat lower on the lateral than on the medial surface of the condyle. It is not known to what extent the band of insertion is shifted superiorly when there is contracture of the capsule. However, shortening of the capsule walls does change the activity of the mechanoreceptors and thereby the activity of the muscles of mastication (Kraus 1994).



62 Function and structural adaptation of the joint capsule
The primary functions of the capsule are proprioception and nourishment of the fibrocartilaginous joint surfaces. Increased functional loading of the joint can result in either stretching or contraction of the capsule. A chronic loading that exceeds the physiological limits activates the type-IV receptors through inflammation or rupture, resulting in pain.

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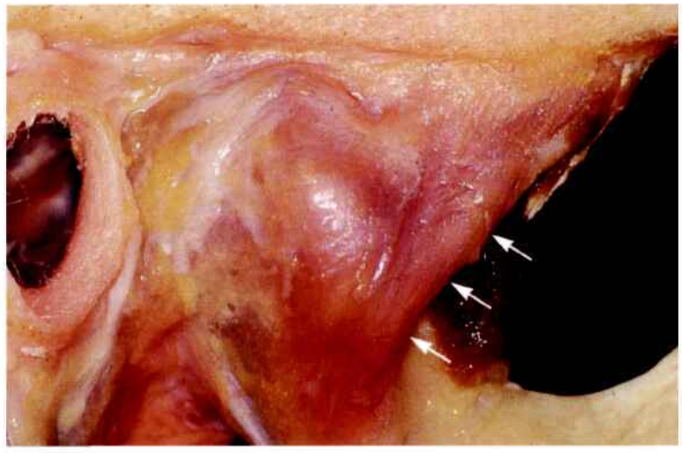
Ligaments of the Masticatory System

The ligaments of the masticatory system, as in all other freely movable joints, have three main functions: stabilization, guidance of movement, and limitation of movement, From a functional view, limitation of movement is the most important function (Mankin and Radin 1979, Osborn 1995). There are different interpretations concerning the number and nomenclature of the ligaments found within the masticatory system (Sato et al. 1995). Five or six ligaments have been described: lateral ligament, stylomandibular ligament, sphenomandibular ligament, discomalleolar (Pinto's) ligament and Tanaka's ligament. Sometimes the collateral attachment fibers between disk and condyle are included in the list as the lateral and medial collateral ligaments of the disk (Yung et al. 1990, Kaplan and Assael 1991, Okeson 1998), although from a functional viewpoint, this is not accurate.

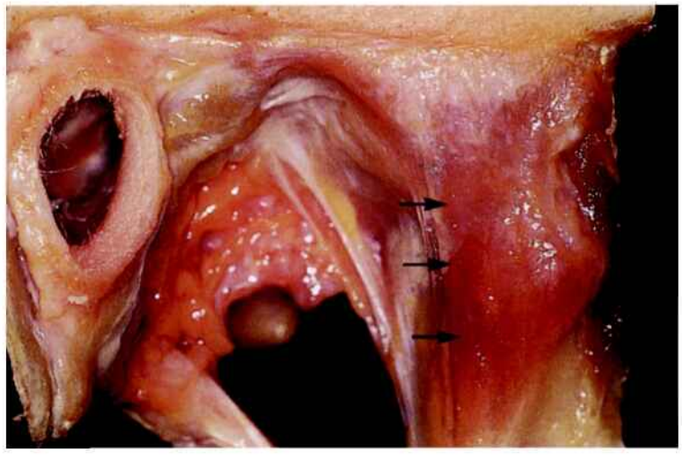
The *lateral ligament* or *temporomandibular ligament* is made up of two parts: a deep, more horizontal part and a superficial, more vertically oriented part (Arstad 1954, Sicher and

Lateral ligament

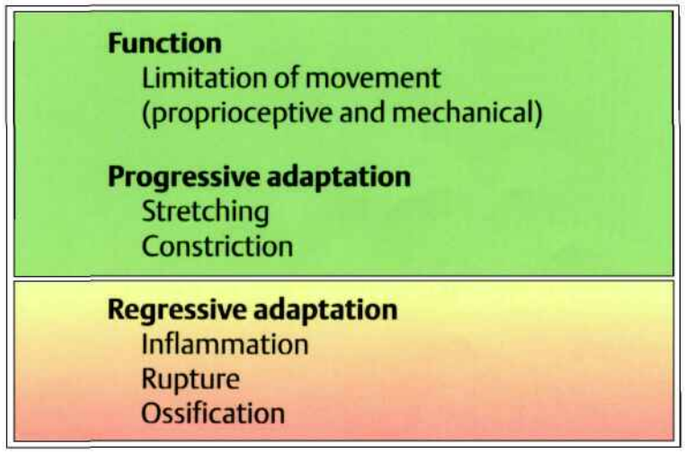
63 Situation with jaws closed
Unlike in formalin-fixed preparations, the lateral ligament (arrows) is usually clearly distinguishable in fresh preparations. The initial rotation during an opening movement is limited by the superficial part of the lateral ligament (von Hayek 1937, Burch and Lundeen 1971). Further opening of the jaws can occur only after protrusion has relieved tension on the ligament, following which the ligament is again stressed by renewed rotation (Osborn 1989).



64 Situation with jaws open
Jaw opening is restricted by the length of the lateral ligament from its origin to its insertion. However, if the condyle can slip past the apex of the tubercle (eminence), the ligament (arrows) will no longer have this limiting effect. In addition, the lateral ligament will now impede retrusive and laterotrusive movements of the condyle (Posselt 1958, Brown 1975, Osborn 1989).



65 Function and structural adaptation of the ligaments
The chief function of the ligaments is to limit movement and thereby protect sensitive structures. In addition, they stabilize the joint and take over guidance functions (Rocabado and Iglarsh 1991). Depending upon the proportions of the types of collagen within the ligament and the direction of the functional overload on the joint, ligaments may become either stretched or shortened.



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DuBrul 1975, Kurokawa 1986). The horizontal part limits retrusion (Hylander 1992) as well as laterotrusion (DuBrul 1980) and thereby protects the sensitive bilaminar zone from injury. The vertical part of the lateral ligament, on the other hand, limits jaw opening (Osborn 1989, Hesse and Hansson 1988). The superficial portions of the lateral ligament contain Golgi tendon organs (Thilander 1961). These nerve endings are very important for the neuromuscular monitoring of mandibular movements (Hannam and Sessle 1994, Sato et al. 1995). For this reason, anesthetizing the lateral portion of the joint permits a 10-15% increase in jaw opening (Posselt and Thilander 1961).

The *stylomandibular ligament* is a part of the deep fascia of the neck and runs from the styloid process to the posterior edge of the angle of the mandible. While part of the ligament inserts onto the mandible, its largest part radiates into the fascia of the medial pterygoid muscle (Sicher and DuBrul 1975). Although the stylomandibular ligament is relaxed during jaw opening, it restricts protrusive and mediotrusive movements (Burch 1970, Hesse and Hansson 1988). Even so, it should prevent excessive upward rotation of the mandible (Burch 1970), which sometimes causes problems in patients with a significantly reduced vertical dimension.

Stylomandibular ligament

66 Situation with jaws closed
Lateral view of a macroscopic anatomical preparation approximating the habitual condylar position. The ligament runs from the styloid process (1) to the posterior border of the angle of the jaw. In this mandibular position the ligament (arrows) is essentially free of tension.
Chronic nonphysiological loading (Fig. 68) can lead to insertion tendinosis (Ernest syndrome; Brown 1996).

67 Situation during rotational jaw opening
Preparation shown in Figure 66 after the initial opening rotation. Rotational movement of the condyle against the articular protuberance causes a relaxation of the ligament (arrows). With further rotational opening, the angle of the jaw would swing farther posteriorly and allow even more slack in the ligament.

68 Situation during translation
Same preparation following anterior translation (= protrusion). Anterior translational movements in the temporomandibular joint always increase tension in the ligament (arrows). This helps to protect more sensitive structures (such as the superior stratum) from overextension during protrusion. Excessive closing rotation of edentulous jaws can likewise produce tension in the ligament.

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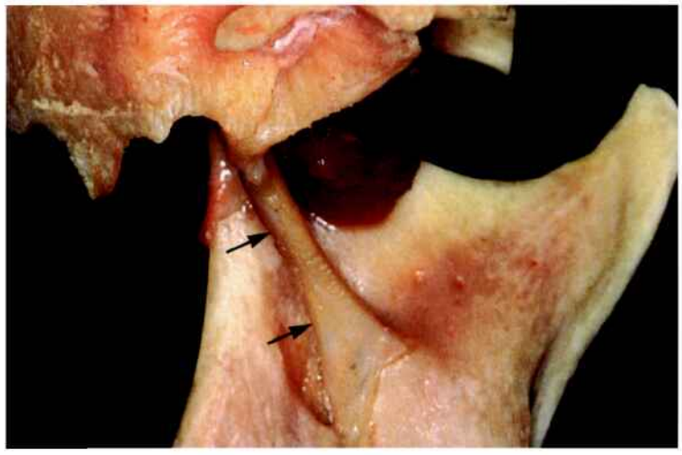
The *sphenomandibular ligament* has its sole origin on the sphenoidal spine in only about one-third of patients (Burch 1966). In the majority of individuals it also inserts into the medial wall of the joint capsule, in the petrotympanic fissure or on the anterior ligament of malleus (Cameron 1915, Loughner et al. 1989, Schmolke 1994). By means of its insertion on the lingula of the mandible, the sphenomandibular ligament limits protrusive and mediotrusive movement (Langton and Eggleton 1992) as well as passive jaw opening (Hesse and Hansson 1988, Osborn 1989). The importance of the sphenomandibular ligament to the physiology of movement is negligible in comparison with the previously described ligaments (Williams et al. 1989), as is confirmed by the lack of related clinical symptoms.

The *discomalleolar ligament (= Pinto's ligament)* was described by Pinto (1962) as a connection between the malleus and the medial wall of the joint capsule. However, a separate ligament can be demonstrated here in only 29% of temporomandibular joints (Loughner et al. 1989).

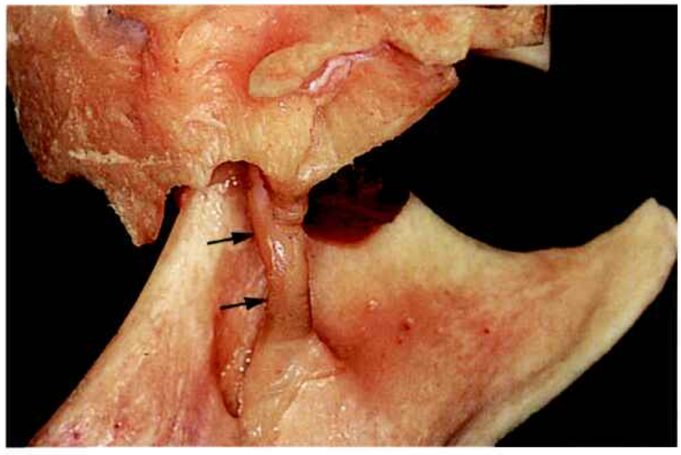
Tanaka's ligament represents a cord-like reinforcement of the medial capsule wall, similar to the lateral ligament (Tanaka 1986, 1988).

Sphenomandibular ligament

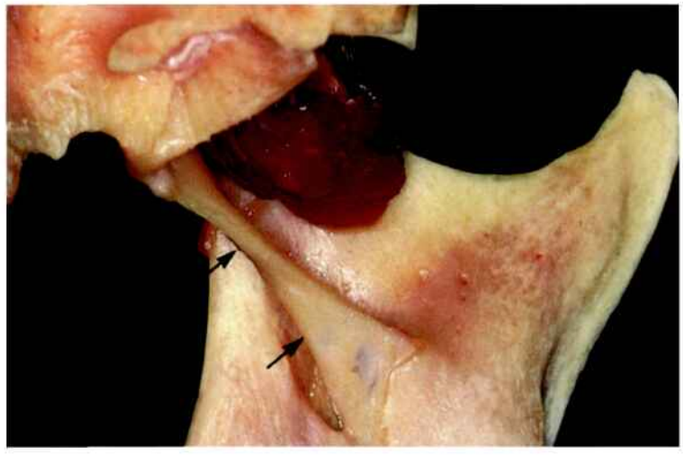
69 Situation at the habitual condylar position
Macroscopic anatomical preparation displaying the left sphenomandibular ligament from the medial. The ligament runs from the spine on the underside of the sphenoid bone (spina ossis sphenoidalis) to the lingula of the mandible (Rodriguez-Vazquez et al. 1992). With the jaws in this position the ligament (arrows) is essentially relaxed. Besides the ligament, a section of the lateral pterygoid muscle can be seen.



70 Situation during opening rotation
Same preparation after opening rotation. As long as the condlye is rotating against the articular protuberance without leaving the fossa, the ligament (arrows) becomes progressively more relaxed. Only after translation begins does the ligament re-acquire the same degree of tension it had when the jaws were closed.



71 Situation during translation
Macroscopic anatomical preparation after anterior translation (= protrusion). In synergy with the stylomandibular ligament, tension in this ligament is increased as translation progresses. The stylomandibular and sphenomandibular ligaments together restrain protrusive and mediotrusive movements. If a pain-producing lesion in one of these ligaments is suspected, passive movements must be used to test the ligaments.



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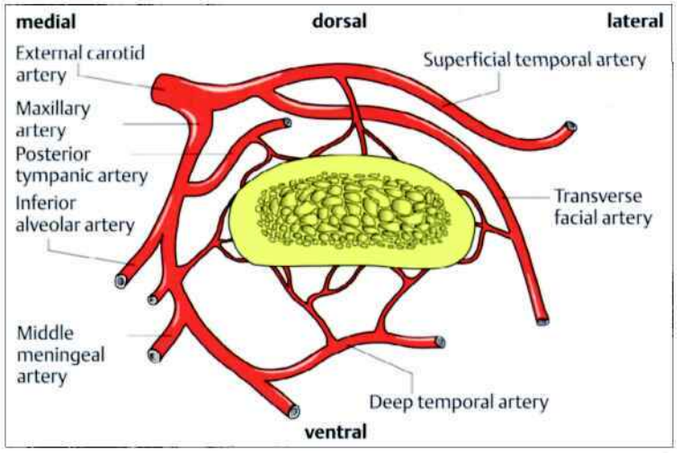
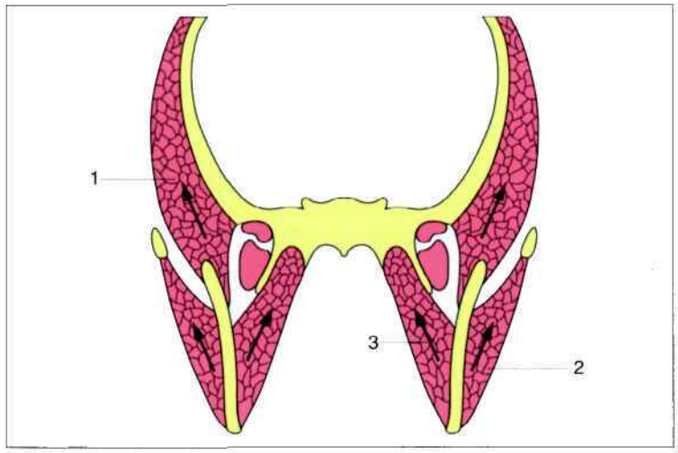
Arterial Supply and Sensory Innervation of the Temporomandibular Joint

The arterial blood supply of the temporomandibular joint is provided primarily by the maxillary artery and the superficial temporal artery (Boyer et al. 1964). Both of these arteries are also the principle supply for the muscles of mastication. Apart from the network of arteries surrounding it, the condyle is also supplied from the inferior alveolar artery through the bone marrow (Okeson 1998). The venous drainage is through the superficial temporal vein, the maxillary plexus, and the pterygoid plexus.

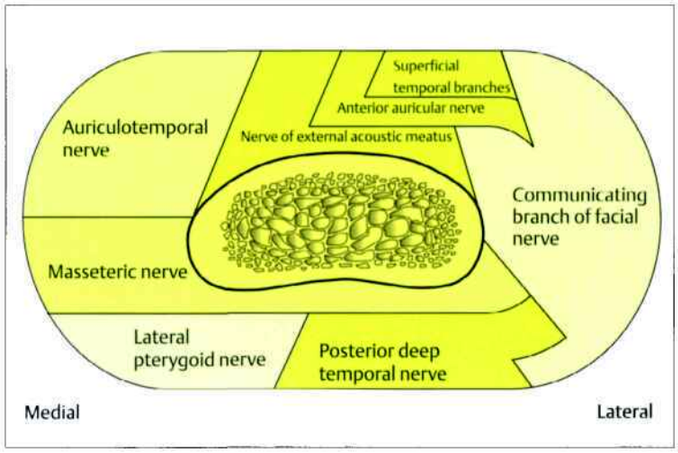
The sensory innervation of the joint capsule and its receptors has already been addressed briefly on page 27. The temporomandibular joint is innervated predominantly by the auriculotemporal, masseter, and temporal nerves (Klineberg et al. 1970, Harris and Griffin 1975). Proprioception occurs through four types of receptors (Thilander 1961, Clark and Wyke 1974, Zimny 1988): Ruffini mechanoreceptors (type I), pacinian corpuscles (type II), Golgi tendon organs (type III), and free nerve endings (type IV). These receptors are located in the joint capsule, the lateral ligament, and in the bilaminar zone and its genu vasculosum. The anteromedial portion of the capsule contains relatively few pain receptors, of type IV (Thilander 1961).



72 Arterial supply
Diagram of the arterial blood supply of a left temporomandibular joint (modified after Voy and Fuchs 1980). The condyle is supplied with blood from all four sides. In addition, there are anastomoses with the inferior alveolar artery within the marrow spaces. Because of the abundant blood supply, avascular necrosis is rarely found in the condyle (Hatcher et al. 1997). Compression of the anterior vessels by anterior disk displacement (Schellhas et al. 1992) will not interfere with the condyle's blood supply.



73 Sensory innervation of a left temporomandibular joint
The afferent nerve fibers arise from the mandibular branch of the trigeminal nerve and exhibit four types of nerve endings. In rats, free nerve endings (type IV), which are potential pain receptors, have been found in the capsule, lateral ligament, bilaminar zone, and in the pars anterior and pars posterior of the disk (Ichikawa et al. 1990, Kido et al. 1991). This has not been verified for human disk structures, however.



74 Innervation in the capsule region
Schematic diagram of the different areas of innervation (modified from Ishibashi 1974, Schwarzer 1993). Activation of the type-IV receptors in the capsule increases the activity of sympathetic efferent fibers (Roberts and Elardo 1985). Because of the sympathetic innervation of the intrafusal muscle fibers (Grassi et al. 1993), a secondary rise in muscle tone is brought about by activation of the afferent fibers of the muscle spindles and the efferent α-motoneurons (Schwarzer 1993).

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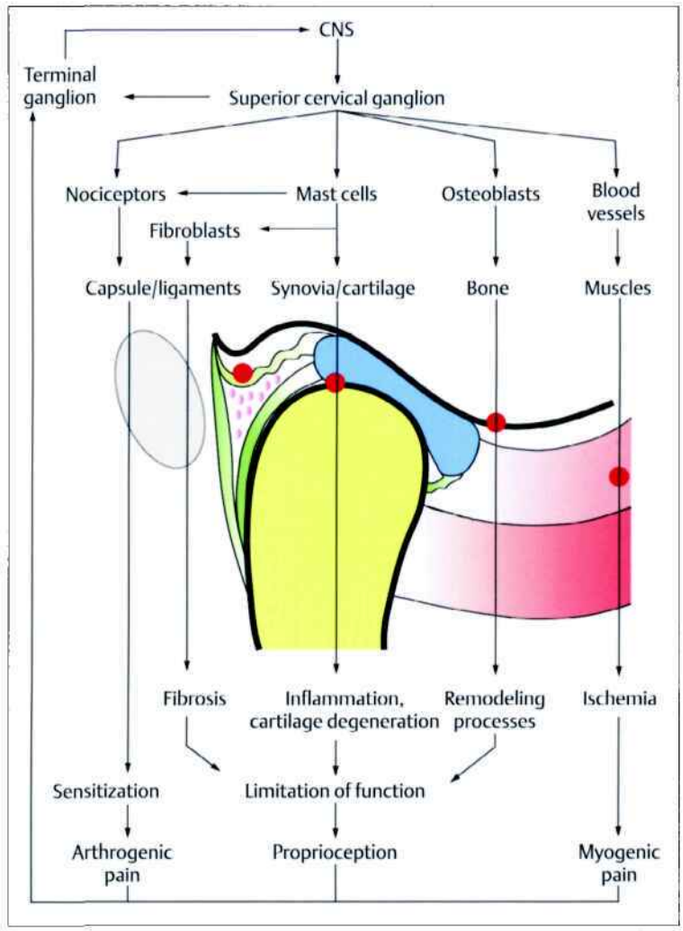
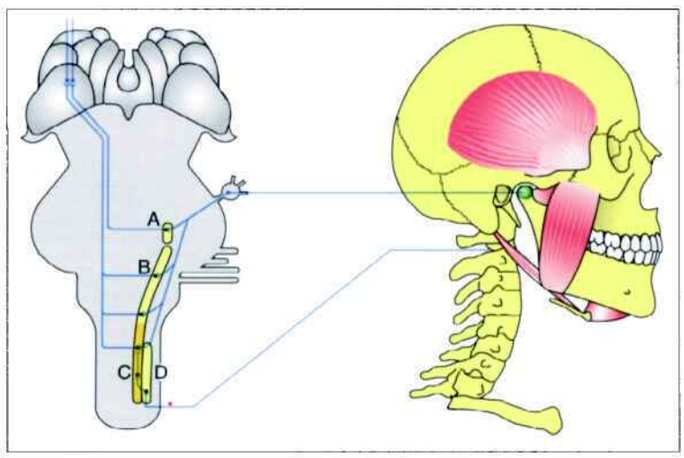
Sympathetic Innervation of the Temporomandibular Joint

The sympathetic innervation of the temporomandibular joint comes from the superior cervical ganglion (Biaggi 1982, Widenfalk and Wiberg 1990). Neurons with the neuropeptides CGRP (calcitonin gene-related peptide) and SP (substance P), that are associated with the sensory nervous system, are found chiefly in the anterior part of the joint capsule (Kido et al. 1993). Sympathetic fibers containing neuropeptide A (NA), Y (NPY), or VIP (vasoactive intestinal peptide) are more numerous in the posterior part of the joint. The ratio of sympathetic to sensory nerve fibers is approximately 3:1 in the temporomandibular joint (Schwarzer 1993). Sympathetic neurons serve primarily for monitoring the vasomotor status. This monitoring allows optimal adjustment of the blood volume in the genu vasculosum during excursive and incursive condylar movements. There is evidence that, in addition to the vasomotor effect, the sympathetic nervous system also plays a role in pain perception (Roberts 1986, Jähnig 1990, McLachlan et al. 1993). Both NA and SP effect the release of prostaglandins, which heighten the sensitivity of pain receptors (Levine et al. 1986, Lotz et al. 1987).



75 Effects of the sympathetic nervous system on the temporomandibular joint
Certain neuropeptides can increase the sensitivity of nociceptors and thereby directly influence pain perception. Special importance has been attributed to the neuropeptides SP and CCRP in the production of synovial cells (Shimizu et al. 1996). Bone remodeling processes are likewise guided by neuropeptides. A nonphysiological increase of pressure within the genu vasculosum caused by a sympathetic or hormonal malfunction during incursive condylar movement results in an anteriorly directed force on the articular disk (Ward et al. 1990, Graber 1991) and this can contribute to an anterior disk displacement. (Revised drawing from Schwarzer 1983.)



76 Afferent paths of the trigeminal nerve and conections of neurons in the brain stem
Schematic representation of the interrelationships between afferent fibers of the trigeminal nerve and the so-called nociceptive specific (NS) neurons and/or the wide dynamic range (WDR) neurons (Dubner and Bennett 1983, Sessle 1987a, b) in the region of the cervical spinal column. The specific connections (A-D) in the sensory trigeminal nucleus in the brain stem can result in identical perceptions in the cortex regardless of where the pain was first perceived.

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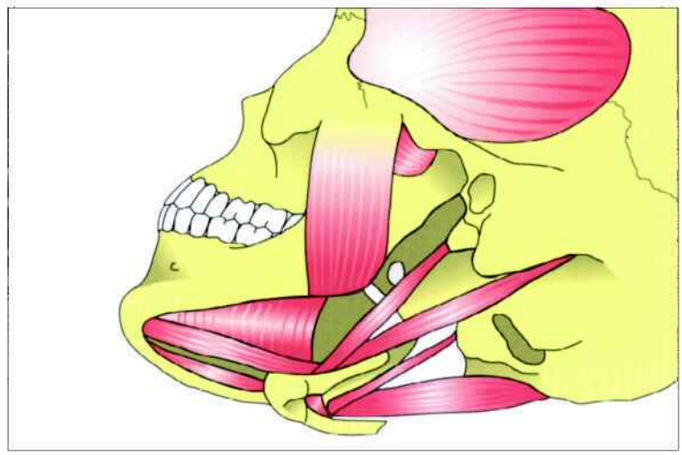
Muscles of Mastication

Anatomically the muscles of mastication can be divided into simple and complex muscles (Hannam 1994, 1997). The lateral pterygoid and the digastric muscles are counted among the simple muscles. These muscles work through a favorable lever arm relative to the joint and so do not have to produce a great deal of force to bring about functional mandibular movements. The parallel muscle fibers in these muscles have their sarcomeres arranged in series, and these are responsible for the adequate muscle contraction. During contraction, the diameter of each muscle increases and is at its greatest near the midpoint of the muscle.

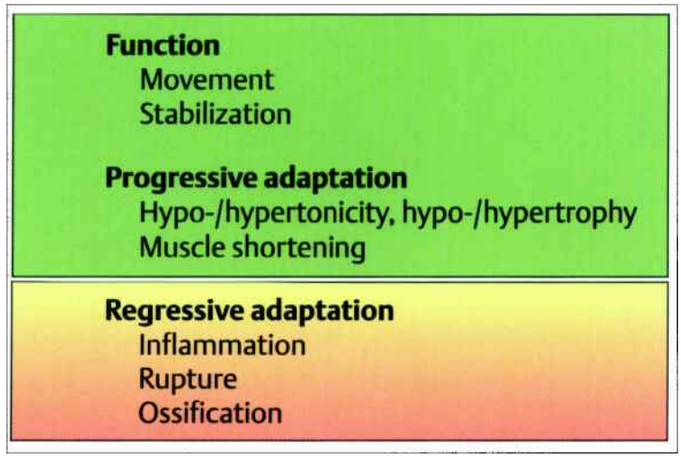
In contrast, the complex muscles include the temporal, masseter, and medial pterygoid muscles with their many aponeuroses and varying sizes. During function the aponeuroses can shift and become deformed (Langenbach et al. 1994). The muscle fibers in this group run obliquely and increase their angle to one another during contractions. A complex muscle can produce a force of approximately 30-40 N per cm2 of cross-section (Korioth et al. 1992, Weijs and van Spronsen 1992). The orientation of the muscle fibers and their facultative activation during various mandibular movements is one of the reasons that muscle symptoms can be reproducibly provoked by loading in one certain direction but not in others. Although there are recurrent principles in muscle architecture (Hannam and McMillan 1994), variations in the areas of muscle attachment and differences in intramuscular structure have an effect on craniofacial development (Eschler 1969, Lam et al. 1991, Tonndorf 1993, Holtgrave and Müller 1993, Goto et al. 1995).

The motor units in the muscles of mastication are small and seldom extend beyond the septal boundaries (Tonndorf and Hannam 1997). The "red" muscle fibers (with higher myoglobin content) contract slowly. They maintain postural positions and are slow to become fatigued. The "white" fibers (with lower myoglobin content) have fewer mitochondria and can contract more rapidly, but they fatigue sooner because of their predominantly anaerobic metabolism. The muscles of mastication are composed of varying mixtures of fibers of types I, IIA, IIB, IIC, and IM (Mao et al. 1992, Stal 1994).

Next, the four chewing muscles proper (temporal, masseter, medial pterygoid, and lateral pterygoid) and the suprahyoid and perioral musculature will be described in preparation for the clinical examination that will be addressed later.



77 Muscles of mastication
Drawing of the muscles of mastication. In the narrowest sense these include only the temporal, masseter, medial pterygoid, and lateral pterygoid muscles. The suprahyoidal musculature is also shown here because it is of interest in the diagnosis and treatment of functional disturbances. The sternocleidomastoid muscle is not included here because it belongs to the musculature of the neck.



78 Function and structural adaptation of the muscles of mastication
Antagonistic muscle activity serves not only to execute mandibular movements, but also helps stabilize the joints. Functional demands can bring about changes in tonus, response to stimuli, and muscle length. Adaptation depends upon the combination of fibers present. Chronic overloading may lead to inflammation, ruptures, or ossification.

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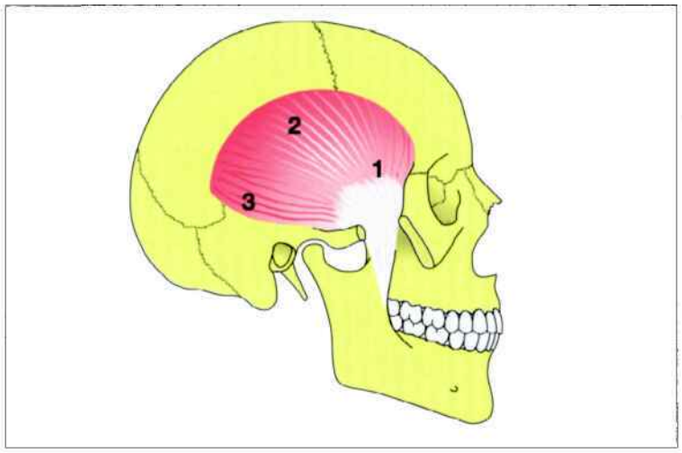
Temporal Muscle

The temporal muscle is a compartmentalized muscle that arises from the superior and inferior temporal lines of the temporal bone. It inserts on the coronoid process and on the anterior edge of the ascending ramus of the mandible. Three functional parts can be distinguished (Zwijnenburg et al. 1996). The anterior part has muscle fibers that pull upward and serve as elevators (Moller 1966). The middle part effects closure of the jaws and, with a posterior vector, retrusion (Blanksma and van Eijden 1990). According to DuBrul (1980) the posterior part is involved primarily with jaw closure and only to a minimal extent with retrusion. Nevertheless, experimental studies have revealed a distinct retrusion when the posterior part is activated (Zwijnenburg et al. 1996). During normal opening and closing movements, as well as during tooth clenching, the activity in all three parts is at a nearly equal high level. During chewing, however, there are great differences between the anterior and posterior parts. The activity is greater on the working side than on balancing side (Blanksma and van Eijden 1995). During lateral jaw movement, EMG activity is markedly lower where there is canine guidance than where there is group function (Manns et al. 1987).

79 Macroscopic anatomical preparation
The pars anterior and pars media of the temporal muscle consist of approximately 47% fatigue-resistant type-I muscle fibers with a low threshold of stimulation (Eriksson and Thornell 1983). The content of thinner type-IIB fibers is about 45%, leading to a higher concentration of fibers in the muscle (Stalberg et al. 1986). Type-IIA muscle fibers are not present at all and those of type IIC and/or IM account for only about 4% (Ringqvist 1974).

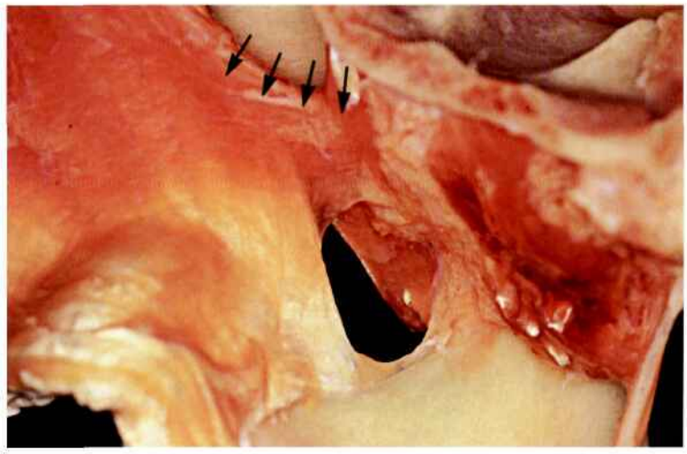
From the collection of B. Tillmann

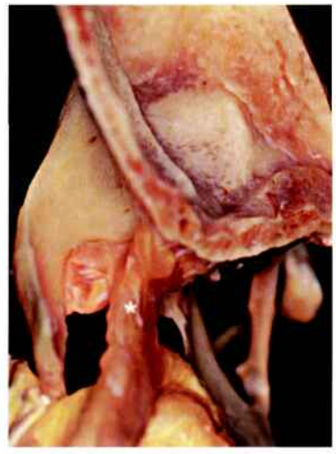
80 Schematic drawing of the right temporal muscle
The muscle comprises a pars anterior (1), pars media (2), and pars posterior (3).
Although the sarcomere lengths are the same in the various parts, there are significant differences in the lengths of the muscle-fiber bundles (21.7-28.9 mm) which indicates different functional demands (van Eijden et al. 1996).



81 Insertion of the temporal muscle on the disk-capsule complex
Left: Medial view. Some of the horizontal fibers (arrows) insert onto the middle and lateral third of the disk (Merida Velasco et al. 1993, Bade et al. 1994).

Right: Insertion of the temporal muscle viewed from above. Easily identified is the tendon (*) of the pars posterior, which inserts on the lateral portion of the disk-condyle complex.





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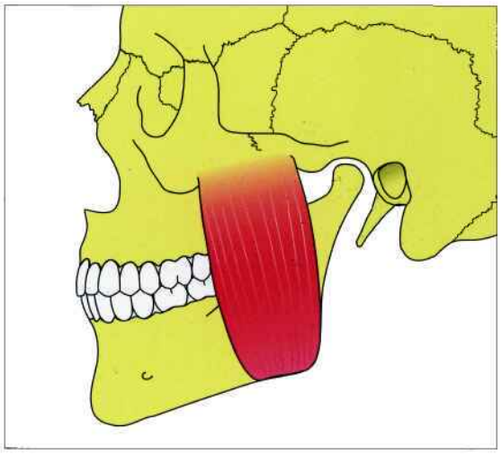
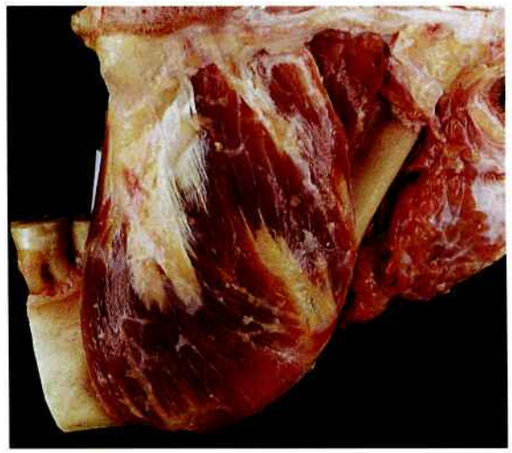
MasseterMuscle

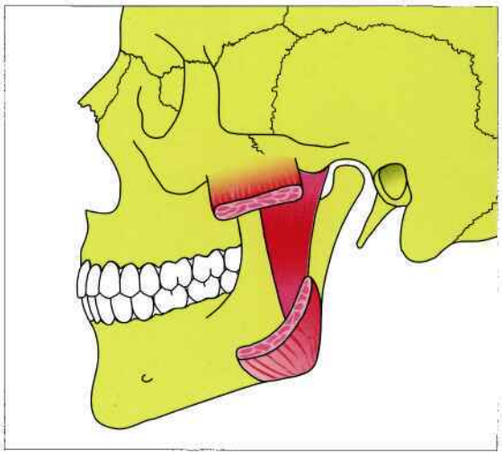
The masseter muscle consists of a superficial and a deep part. The origin of the superficial part is on the zygomatic arch and its insertion is on the lateral masseteric tuberosity at the angle of the mandible. The deep part also arises on the zygomatic arch but inserts on the lateral surface of the ascending ramus. Portions of the deep part also insert on the joint capsule and the disk (Frommer and Monroe 1966, Meyenberg et al. 1986, Dauber 1987). In this way the masseter can influence the capsule receptors by changing the capsule tension. The lowest EMG activity and the greatest chewing force in this muscle can be demonstrated at a jaw opening of 15-20 mm (Manns et al. 1979, Lindauer et al. 1993, Morimoto et al. 1996). Seventy-four percent of the masseter's muscle spindles are to be found in the deep part (Eriksson and Thornell 1987). These muscle spindles have large diameters and a four-fold higher concentration of intrafusal fibers. From this it can be deduced that there are special functions for different areas of the muscle. The masseter muscle shows no significant difference in EMG activity between subjects with canine guidance and those with group function (Borromeo et al. 1995).

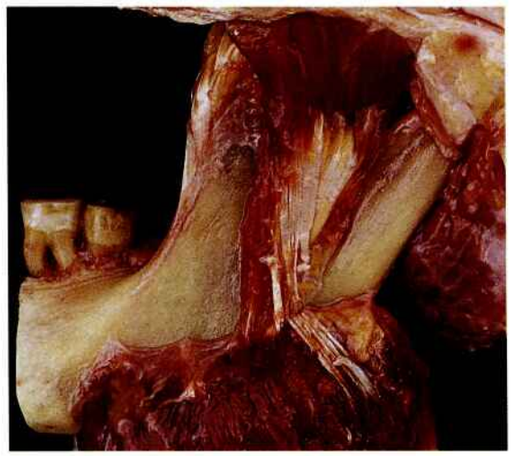




82 Pars superficialis of the masseter muscle
Left: Schematic drawing of the pars superficialis. The masseter has a higher concentration of capillaries relative to the diameter of the fibers than all the other skeletal muscles (Stal et al. 1996).

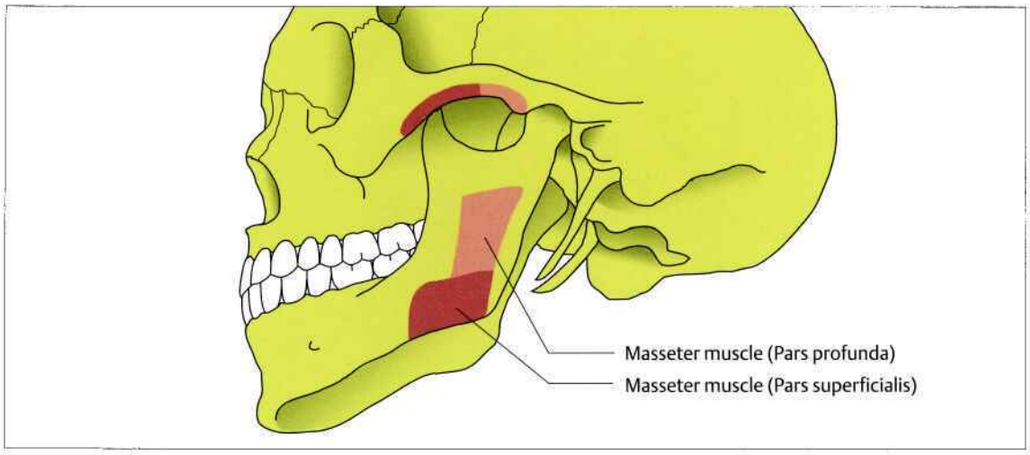
Right Macroscopic anatomical preparation of the masseter muscle. The resultant force of the pars superficialis is in an anterosuperior direction. The posterior part of the pars superficialis is composed of up to 45% type-IIB fibers (Eriksson and Thornell 1983), which have a high threshold and are fatigue-resistant.





83 Pars profunda
Left: Schematic drawing.

Right: The pars profunda revealed in an anatomical dissection. The muscle has a relatively broad insertion on the zygomatic arch from which it pulls on the lateral surface of the ascending ramus of the mandible. The posterior part of the pars profunda also inserts into the lateral third of the disk-capsule complex (Merida Velasco et al. 1993, Bade et al. 1994). Only approximately 25% of the muscle fibers of the pars profunda are of type IIB.



84 Origin and insertion of the masseter muscle
Schematic drawing showing the areas of origin and insertion of the masseter muscle. The origin of the pars superficialis is on the inferior surface of the zygomatic arch anterior to that of the pars profunda. The insertion of the pars superficialis lies on the lateral surface of the angle of the mandible. At the inferior border of the mandible it is continuous with the medial pterygoid muscle on the inner surface of the mandible. The pars profunda inserts above the masseteric tuberosity on the ascending ramus of the mandible.

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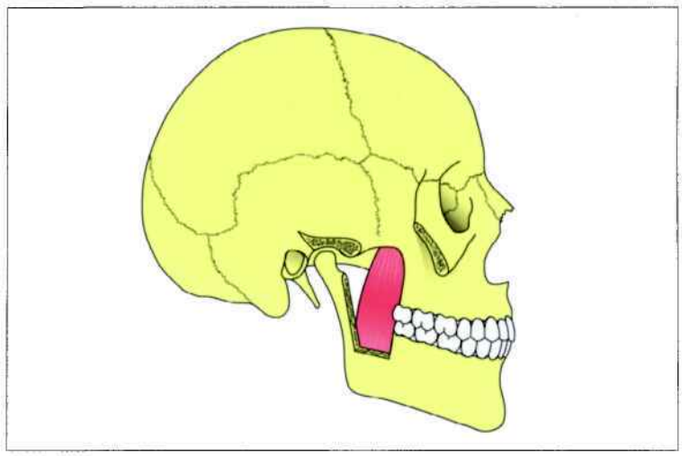
Medial Pterygoid Muscle

The medial pterygoid muscle, together with the temporal and masseter muscles, are the *jaw-dosing muscles.* This muscle has its origin in the pterygoid fossa of the pterygoid process of the sphenoid bone. From there it extends inferiorly, posteriorly, and laterally to the inner side of the angle of the mandible, where it connects with the masseter to form a muscle sling. The course of the medial pterygoid muscle closely parallels that of the pars superficialis of the masseter. The medial pterygoid muscle functions primarily during jaw closure, but also takes part in protrusive movements. Unilateral contraction results in mediotrusion. Because of its oblique course in the frontal plane, this muscle also influences the transverse position of the condyle. Unlike the temporal and masseter muscles, the medial pterygoid cannot be adequately palpated except for its insertion. Its activity in protrusive position increases with the number and size of tooth contacts (MacDonald and Hannam 1984, Wood 1986). Tooth gnashing in a posterior direction is accompanied by a greater increase in EMG activity than in anteriorly directed gnashing (Vitti and Basmajian 1977).

85 Posterior view of the medial pterygoid muscles in the frontal plane
This preparation clearly reveals the relationship of the medial pterygoid muscles (1) to the lateral pterygoids (2) and the masseters (3) and the muscular slings they form with the latter. The strength of a muscle depends on its cross-sectional area (Sasaki et al. 1989). In patients with dentitions damaged by periodontal disease, the chewing force was found to be reduced by 25% in the masseters and 10% in the medial pterygoids (Gilbert and Newton 1997).

86 Schematic drawing of the medial pterygoid muscle
Like the pars superficialis of the masseter, the composition of the anterior part of the medial pterygoid is 64% type-I muscle fibers (low threshold, fatigue-resistant) and 27.5% type-IIB (high threshold, fatigue-resistant) (Eriksson and Thornell 1983). In the posterior part, on the other hand, 44% of the fibers are of type I and 45% are of type IIB.



87 Medial view of an anatomical dissection of a right medial pterygoid muscle (1)
The muscle runs inferiorly and posteriorly from the fossa of the pterygoid process to the inner side of the angle of the mandible. As in the masseter, the muscle fibers are extensively interlaced with no uniform direction of alignment. They are comparatively short, but have a relatively large cross-section (van Eijden et al. 1995).

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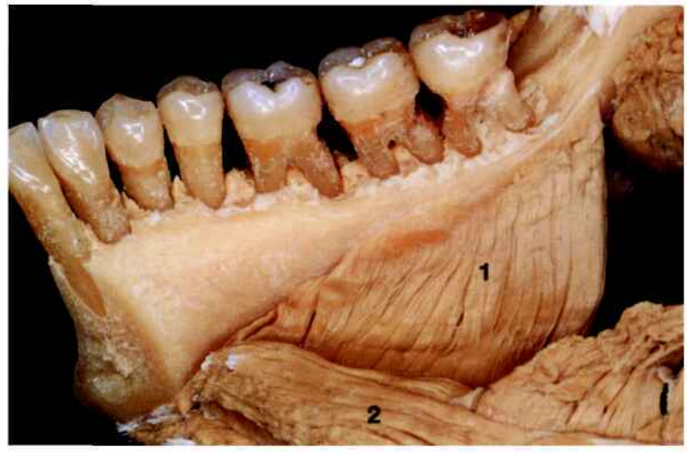
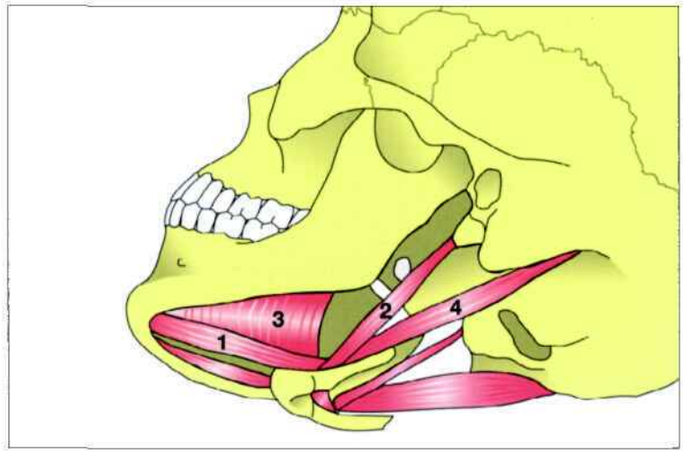
Suprahyoid Musculature

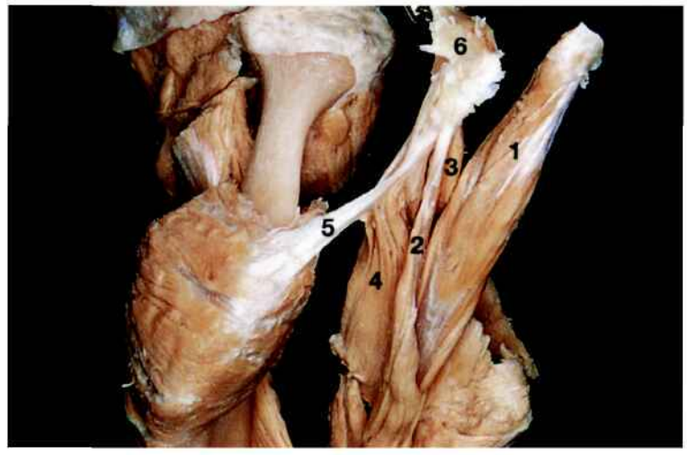
The suprahyoid muscles, together with the lateral pterygoids, make up the *jaw-opening muscles.* The suprahyoid musculature includes the digastric, mylohyoid, geniohyoid, and stylohyoid muscles. The *digastric muscle* has two bellies. The posterior belly has its origin medial to the mastoid process and extends anteriorly, inferiorly, and medially to the hyoid bone; here it attaches to the bone and connects with the anterior belly by means of an intermediate tendon. The anterior belly inserts in the digastric fossa on the inner side of the mandible. When the hyoid bone is braced by the infrahyoid musculature, contraction of the digastric muscle tends to open and retract the jaw. The *mylohyoid muscle* extends from the step-like myohyoid line on the inner aspect of the body of the mandible to the body of the hyoid bone. The *geniohyoid muscle* arises at the inner side of the mandibular symphysis, and from there its parallel fibers run directly to the body of the hyoid bone. The pair of geniohyoid muscles can function together as jaw openers, but they can also lift the floor of the mouth and pull the hyoid bone forward. The *stylohyoid muscle* runs from the styloid process of the temporal bone to the greater horn of the hyoid and serves to stabilize the hyoid.



88 Mylohyoid muscle
Anatomical preparation of a right mylohyoid muscle (1). The anterior and middle fibers of the mylohyoid muscle insert in the center at the mylohyoid raphe. The fibers of the posterior portion insert on the hyoid bone under the geniohyoid muscle (2). These muscles are active primarily during jaw opening, swallowing, and protraction of the tongue, but they also show some activity during lateral jaw movements (Vitti and Basmajian 1977).



89 Suprahyoid musculature from a left posteroinferior view
The digastric muscle with its anterior belly (1) and posterior belly (2) can be seen from this perspective. The mylohyoid (3) and stylomandibular (4) muscles are also visible. When the mandible is stabilized by the closing muscles (elevators), contraction of the suprahyoid musculature lifts the hyoid bone. This is an important part of the act of swallowing.



90 Suprahyoid musculature
Posterior view of an anatomical preparation of the left half of the jaw showing the posterior belly of the digastric (1), stylohyoid (2), styloglossus (3), and stylopharyngeus (4) muscles as well as the stylomandibular ligament (5). Except for the digastric muscle, all these structures have their origin on the stylohyoid process (6). Muscle fibers of type I, type HA, and type IIB each make up one-third of the digastric muscle (Eriksson et al. 1982).

From the collection of B. Tillmann (Figures 85, 87, 88, 90)

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Lateral Pterygoid Muscle

The lateral pterygoid muscle is made up of two functionally different parts (McNamara 1973): an upper (superior) head and a lower (inferior) head. In 12% of the specimens studied, Abe et al. (1993) could also identify a third, intermediate muscle belly.

The *upper head* arises on the greater wing of the sphenoid bone. It always has an insertion in the upper portion of the pterygoid fovea, but it may also insert to varying degrees into the disk-capsule complex (Chissin 1906, Troiano 1967, Porter 1970, Mahan et al. 1983, White 1985, Meyenburg et al. 1986, Dauber 1987, Carpentier et al. 1988, Merida Velasco et al. 1993, Bade et al. 1994). In 30-40% of temporomandibular joints, the upper head inserts exclusively on the condyle (Moritz and Ewers 1987, Wilkinson 1988, Luder and Bobst 1991, Heylings et al. 1995, Naidoo and Juniper 1997).

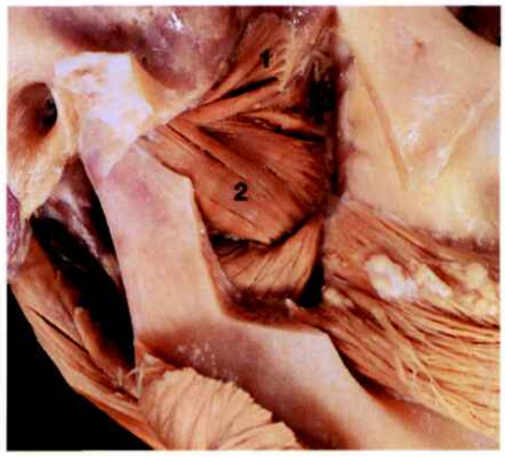
The *lower head* arises on the lateral face of the lateral lamina of the pterygoid process and inserts in the pterygoid fovea. It is possible that fibers from the upper and lower head are intermingled, but in any event, fibers of the lower head can radiate into the disk-capsule complex (Dauber 1987).

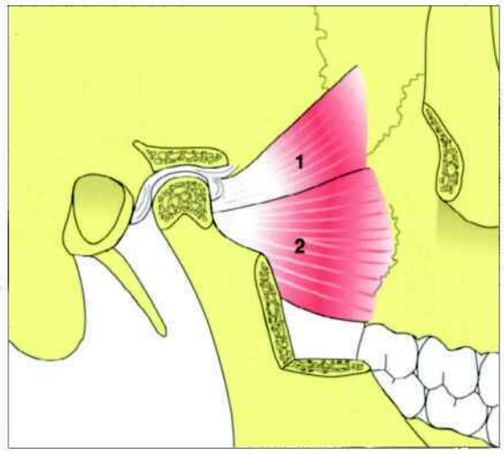
91 Lateral pterygoid muscle
Left: Lateral view of an anatomical preparation. This muscle is characterized by relatively long fiber bundles with small cross-sections (van Eijden et al. 1995) in its upper head (1) and lower head (2). The upper head always inserts on the condyle, and in 60% of specimens it also inserts on the disk-capsule complex.

From the collection of B. Tillmann

Right: Schematic drawing.

1 Upper head
2 Lower head

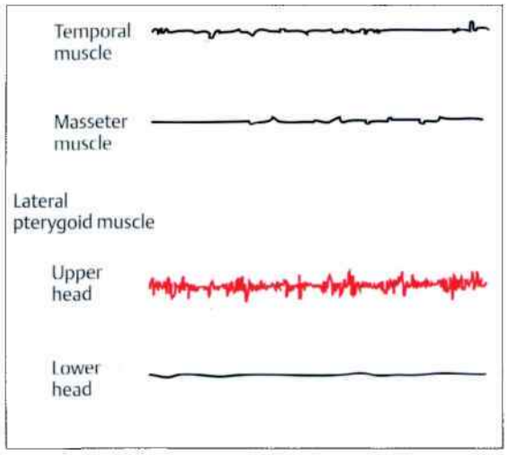


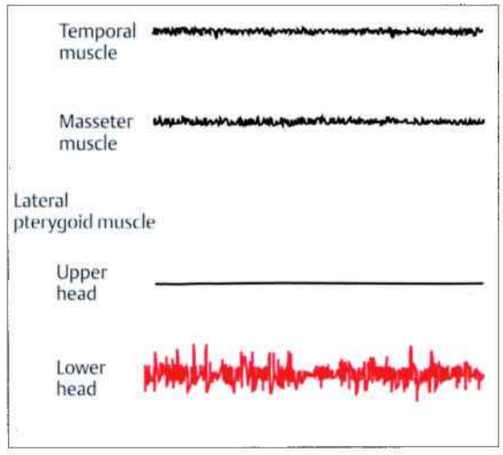


92 EMG activity of the muscles of mastication at rest and during jaw opening
After Juniper 1984

Left: In the relaxed mandibular position only minimal EMG activity can be detected from the upper head of the lateral pterygoid muscle.

Right: During jaw opening the upper head is active and serves to protrude the condyles. Activity of the suprahyoid musculature was not measured in this study.

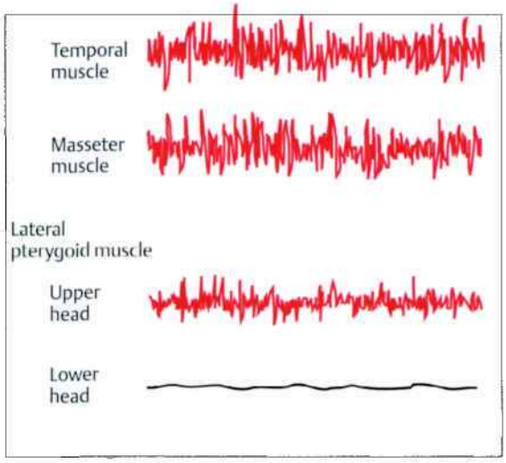


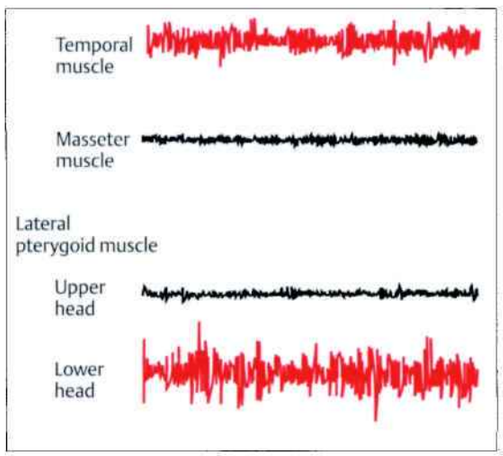


93 EMG activity during grinding of the teeth
After Juniper 1984.

Left: During tooth grinding in maximum occlusion, the two large jaw-closing muscles and the upper head of the lateral pterygoid show a high level of EMG activity.

Right: During grinding of the anterior teeth, the lower head holds the mandible forward and the activity of the elevators decreases because of the reflex inhibition from the periodontium (Widmalm et al. 1987).





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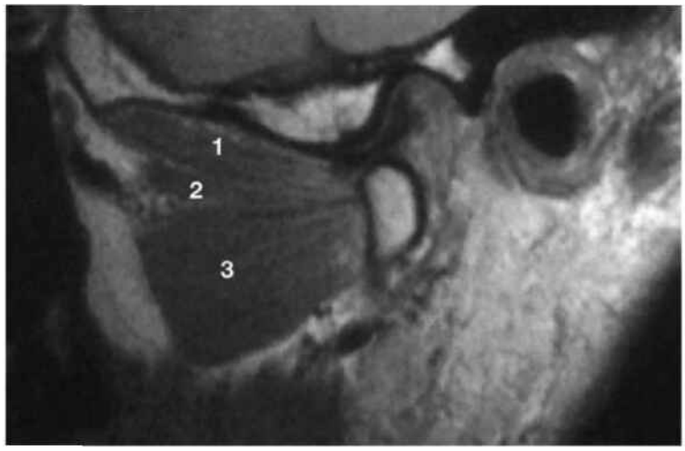
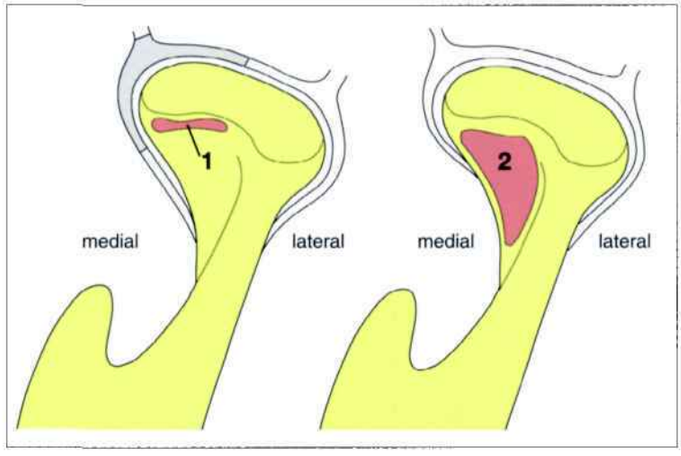
Fibers of the lateral pterygoid muscle were found to insert into the periphery of the disk in 22% of the joints studied. In these cases 88% of the muscle fibers were from the upper head and 12% from the lower head (Abe et al. 1993). The smaller the area of attachment of the lateral pterygoid muscle to the condyle, the greater the tendency for disk displacement (Dreger 1994). The upper and lower heads have an antagonistic action. Numerous EMG studies (Molin 1973; Gibbs et al. 1984; Juniper 1983, 1984; Widmalm et al. 1987; Yoshida 1995) have revealed that the lower head is always active during excursive mandibular movements (jaw opening, protrusion, mediotrusion), whereas the upper head is active during incursive movements (jaw closing, retrusion, laterotrusion), serving to hold the disk-condyle complex continuously against the slope of the eminence and to restrain it during incursive movements (Wood et al. 1986). The high proportion (80%) of type-I muscle fibers (low stimulation threshold, fatigue-resistant) is also indicative of a continuous holding action with a low level of force (Eriksson et al. 1981, Mao et al. 1992). Because the upper head becomes longer during its holding action, this can be referred to as eccentric muscle activity (Wilkinson 1988).

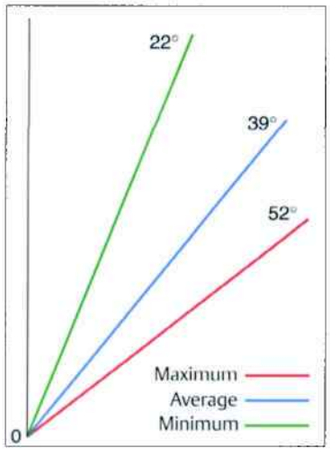


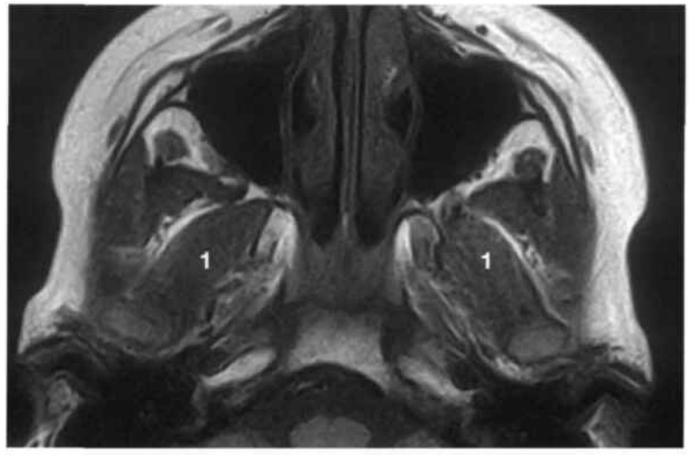
94 MRI of a left lateral pterygoid muscle in the sagittal plane
According to Abe et al. (1993), in 12% of individuals the lateral pterygoid muscle divides into three parts as seen here. According to Ögütcen-Toller and Juniper (1994) the muscle becomes segmented into three parts in week 12 of embryonic development to form an upper (1), middle (2), and lower (3) head.



95 Attachment areas of the lateral pterygoid muscle on the condyle
From Moritz and Ewers 1987.

In agreement with numerous other studies, the upper head always inserts on the condyle (1), and in 60% of joints it also inserts into the anteromedial portion of the disk-capsule complex (gray). The lower head always inserts into the pterygoid fovea (2). An overly strong upper head cannot by itself displace the disk anteriorly.





96 Lateral pterygoid muscles in the horizontal plane
Left: Diagram showing the angulation of the lateral pterygoid muscle to the midsagittal plane (modified from Christiansen et al. 1988). With the jaws closed, the angle averages 39° and ranges from 22° to 52°. In protrusion the origin and insertion come closer together and the angle becomes greater (Okeson 1998).

Right MRI showing the lateral pterygoid muscles (1) in the horizontal plane.

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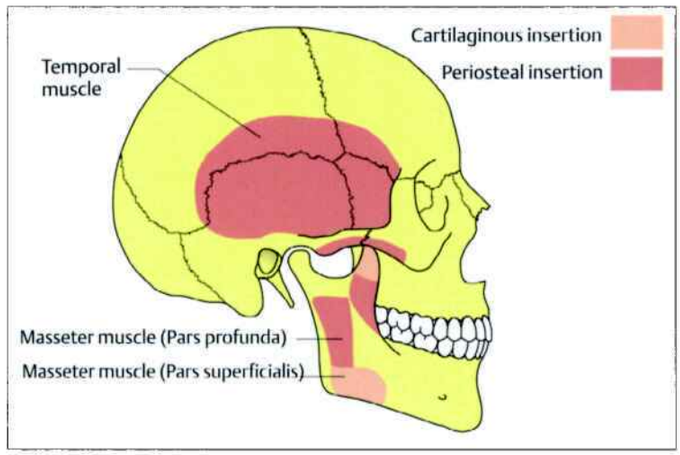
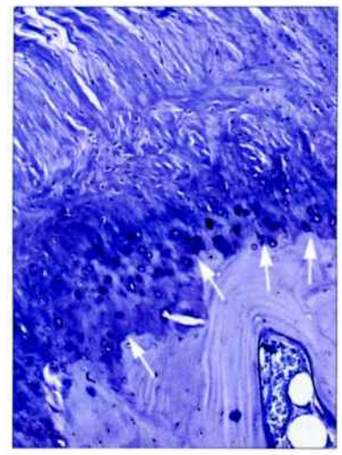
Gross Anatomical and Histological Studies of the Masticatory Muscle Insertions

The tendons of the muscles of mastication attach to bone by means of special insertion structures (Goss 1940, Long 1947, Symons 1954, Cooper and Misol 1970, Chong and Evans 1982). A fundamental distinction must be made between periosteal-diaphyseal insertions (Biermann 1957) and chondral-apophyseal insertions (Knese and Biermann 1958). A periosteal-diaphyseal insertion may be flat or circumscribed. The structural makeup of an insertion should be such that it can equalize the different moduli of elasticity of the tissues. Pathological changes in these areas bring about the clinical picture of insertion tenopathy (Becker and Krahl 1978, Tillmann and Thomas 1982). In the extremities there is a direct relationship between the mode of osteogenesis in the region and the histological makeup of the tendon attachment structures (Evans et al. 1991). This type of relationship has not been demonstrated in the masticatory structures. Insertion tenopathies occur primarily in chondral-apophyseal insertion structures. It has been suggested that the cause lies in a disturbed collagen synthesis combined with a low content of glycosaminoglycans in the fibrocartilaginous tissue (Hems 1995).

97 Muscle origins and insertions on the side of the skull
Left: Schematic drawing showing the origins and insertions of the masseter and temporal muscles. Both muscles have periosteal and cartilaginous areas of insertion.

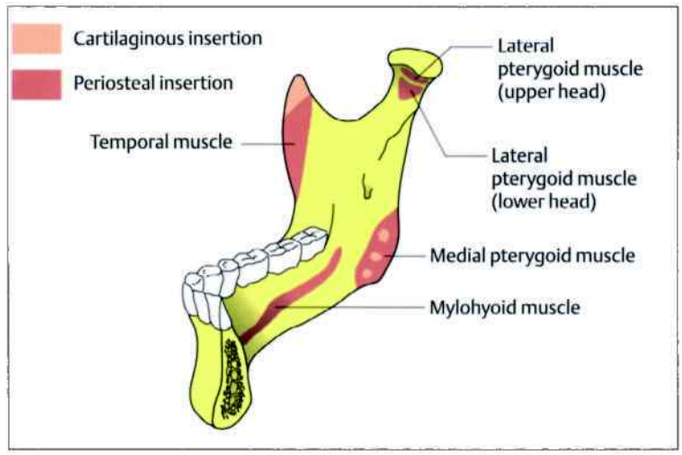
Right: Histological preparation of the insertion of the tendon of the temporal muscle. The tendon inserts on the coronoid process by means of cartilaginous structural elements (arrows).





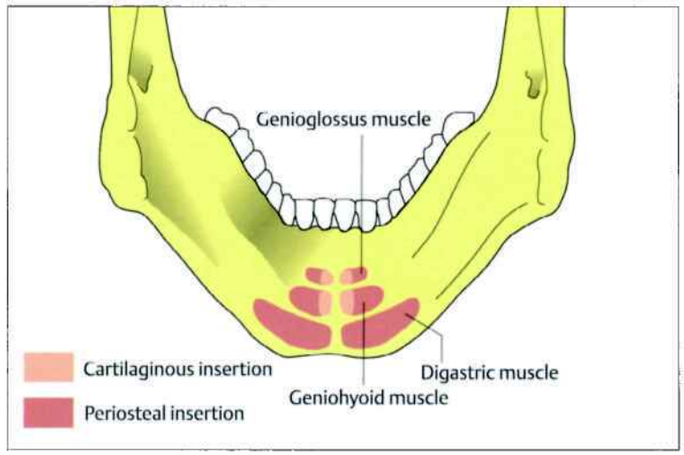
98 Muscle origins and insertions on the medial surface of the mandible
Left: Schematic drawing of the origins and insertions of lateral and medial pterygoid muscles and the mylohyoid muscle. Except for the medial pterygoid, the insertions of all these muscles are entirely periosteal.

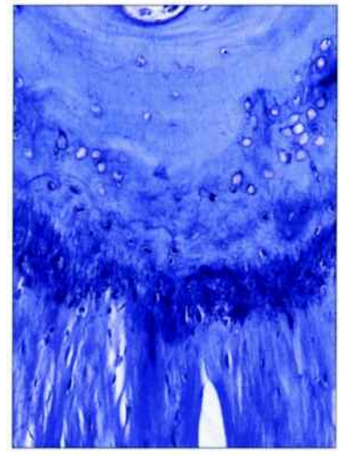
Right: Histological preparation of the insertion of the lateral pterygoid muscle in the pterygoid fovea. The insertion is entirely periosteal (arrows).



99 Muscle origins and insertions on the posterior mental protuberance
Schematic presentation of the origins and insertions of the geniohyoid, genioglossus, and digastric muscles. In this region there are both cartilaginous and periosteal areas of insertion.

Right Histological preparation of the insertion of the digastric muscle. The insertion of this muscle is primarily periosteal, but it does have some regions of cartilaginous insertion.
Histology by B. Tillmann
(Figs. 97-99, right)





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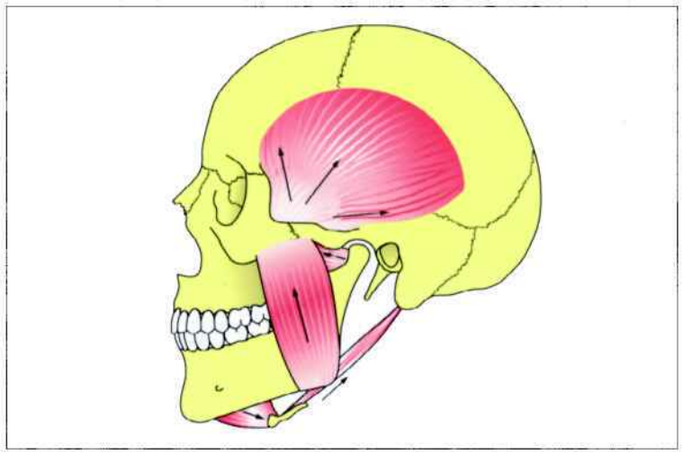
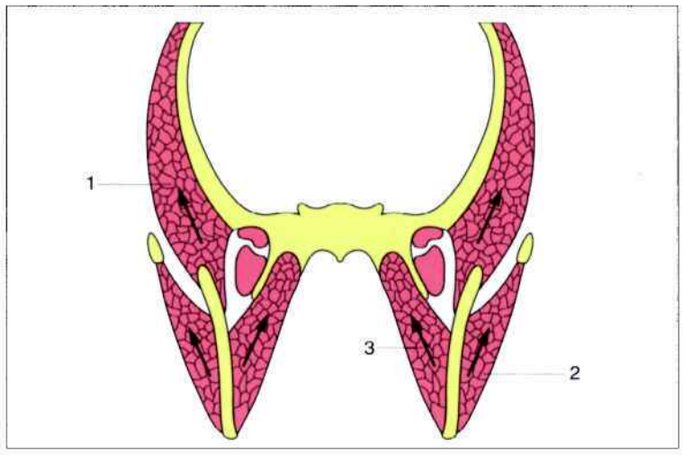
Force Vectors of the Muscles of Mastication

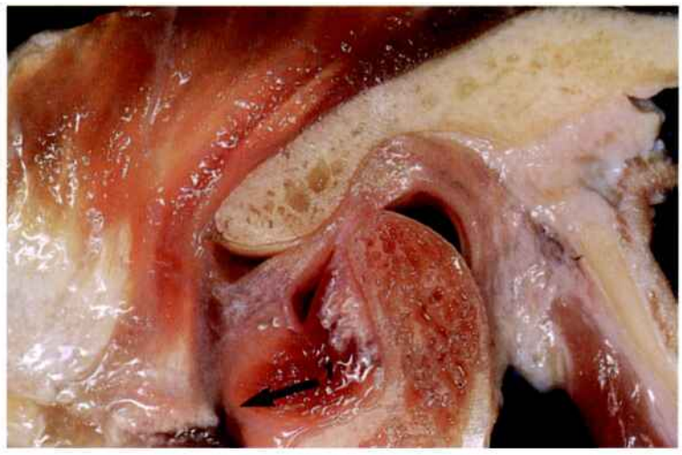
No chewing muscle contracts in isolation. Every muscle contraction contributes to a resultant force vector that acts upon the mandible, the teeth, and the temporomandibular joint (Hannam 1994). From this it follows that only limited parts of a muscle are active during certain functions. In addition, the mandible is an elastic structure and this property can cause the loading vectors to be completely different depending on the muscle activation and the function at the moment (Korioth et al. 1992). The maximum force that a muscle can develop can be calculated from the dimensionless product of its cross-sectional area with a value of approximately 35 (Weijs and Hillen 1984, Korioth et al. 1992). As a general rule, decompensated muscles exhibit a loading vector in the direction of their contraction. Causes for this can be a muscle hypertonus related to central stimuli or the occlusion, or an inflammation of the bilaminar zone. The pattern for complex activation of the muscles of mastication depends much less upon the available muscle force than upon the direction of the resultant force. A complex pattern of activation, therefore, allows for unconscious improvement of the muscle forces for optimum chewing efficiency (Mao and Osborn 1994).



100 Muscle vectors in the sagittal plane
Directions of individual force vectors (arrows). The resultant force on the temporomandibular joint is directed anterosuperiorly. The masseter muscle pulls at an angle of approximately 70° to the occlusal plane and the medial pterygoid muscle at an angle of approximately 80° (Weijs and van Spronsen 1992). Individual variations in these orientations amount to only about 10° (Hagiwara et al. 1994). The physiological cross-sectional area of the temporal muscle ranges from 1.8-2.9 cm^2 (van Eijden et al. 1996).



101 Muscle vectors in the frontal plane
Diagram of the force vectors in the frontal plane (redrawn from Hylander 1992). Through the specific arrangement and activation of the temporal (1), masseter (2), and medial pterygoid (3) muscles, the condyles are directed transversely against the articular protuberance. The direction of the force vectors in the frontal plane is not correlated with the transverse dimensions of the facial skeleton (van Spronsen 1993).



102 Example of a loading vector of the lateral pterygoid muscle
Clinical evidence of a muscle-specific pain in the lateral pterygoid muscle (1) would point to a chronic overloading in the direction of contraction (arrow). The cause could be a centrally stimulated muscle hypertonus or inflammation of the bilaminar zone. In the latter case, the muscle reflexly seeks to relieve pressure on the painful bilaminar zone. Painful decompensation of the lateral pterygoid muscle without lesions in the bilaminar zone has not been observed clinically for a long time.

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Tongue Musculature

The *extrinsic tongue musculature* includes the styloglossus, genioglossus, and hyoglossus muscles. They connect the body of the tongue to the nearby bone structures to give it its ample mobility within the oral cavity (Thiele et al. 1992).

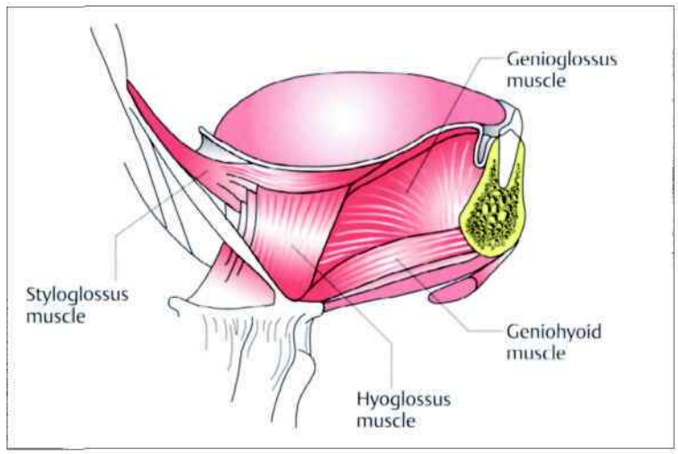
The *intrinsic tongue musculature* is made up of the longitudinal, transverse, and vertical muscles of the tongue. They help to change the shape of the tongue.

While the balanced antagonistic activity of the muscles of mastication contributes to positioning the condyles on the articular protuberance, the activity of the tongue musculature on the lingual tooth surfaces and the muscles of the cheeks and lips on the facial surfaces influence the *position of the teeth in the dental arch.* Even though the tongue has little effect on the joints, afferent information from the joint capsules does indirectly alter the position of the tongue (Lowe 1978).

The occurence of dysphagia and limited motor functions of the tongue have not been proven to be age-dependent. (Caruso and Max 1997, Koshino et al. 1997).

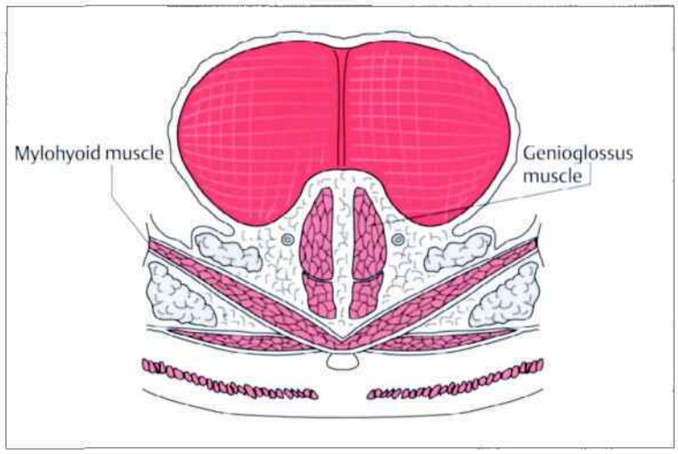
103 Extrinsic tongue musculature

The styloglossus muscles pull the tongue back and up. If one muscle acts unilaterally, the tongue becomes concave. With hypofunction the third phase of the swallowing reflex will be absent (Thiele et al. 1992). The genioglossus can move the dorsum of the tongue downward, pull the border of the tongue forward, and help extend the tongue. Hyperfunction of the genioglossus results in tongue thrusting. The hyoglossus lowers the body of the tongue and pulls the tongue back. Its hyperfunction results in a sunken tongue (Thiele et al. 1992).



104 Intrinsic tongue musculature

Diagram of the internal tongue muscles and their positions in relation to the muscles of the floor of the mouth. The longitudinal muscles of the tongue shorten the tongue. The transverse muscles bring the borders of the tongue closer together. Hypotonus of these fibers leads to a widened tongue. The vertical muscles make the tongue flatter and wider, and their hyperfunction frequently accompanies lateral tongue thrusting, which can cause widening of the dental arch.



105 Function of the tongue muscles

A list of the specific functions of the extrinsic and intrinsic muscles of the tongue and their effects on the body of the tongue (from Thiele et al. 1992). Without the stable buttress formed by the musculature of the floor of the mouth, many dysfunctions of the tongue would not be possible. The floor of the mouth is stabilized differently in different individuals. The act of swallowing does not necessarily involve all the muscles of the floor of the mouth in lifting the hyoid bone (Spiro et al. 1994).

Acting muscle	Effect on the body of the tongue
Styloglossus muscle	High position of the dorsum with tendency for widening; interocclusal position; lateral and palatal thrusting (unilateral and bilateral)
Genioglossus muscle	Forward thrust of the medial portion; low position of the tip; frontal thrust
Hyoglossus muscle	Low position of the body of the tongue; low, lateral tongue thrust
Longitudinalis muscle	Short, thick, wide ball shape
Transverse muscle of tongue	Anterior thrust and interocclusal position
Vertical muscle of tongue	Lateral thrust and interocclusal position

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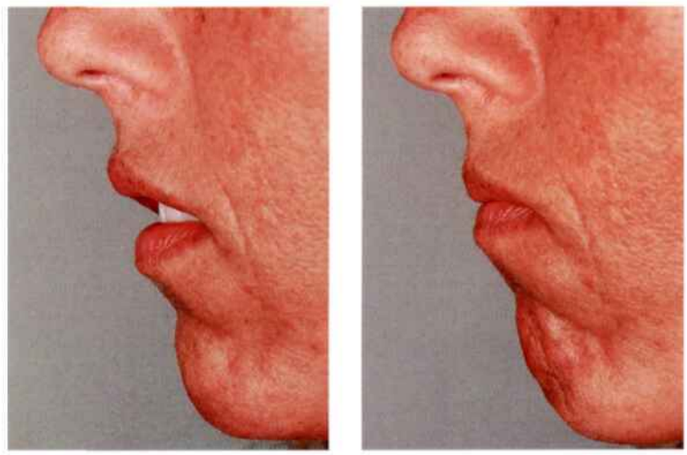
Muscles of Expression

The orofacial musculature is made up of the following muscles: nasalis, depressor septi, levator labii superioris alaeque nasi, orbicularis oris, zygomaticus major, zygomaticus minor, risorius, levator labii superioris, levator anguli oris, depressor anguli oris, depressor labii inferioris, mentalis and platysma myoides. Disturbances in the tonus of these muscles can affect the patient's facial appearance and the position of the teeth within the dental arch (Hoyer and Limbrock 1990, Padovan 1995). In combination with the activation of one or more of the muscles of mastication, they can also influence the condylar position and thereby the loading of the different structures of the joint (Pahkala et al. 1995). The previous statement about the muscles of mastication also holds true for the muscles of expression: no muscle contracts in isolation (Brown 1996). Systematic observation of individual muscles of expression is not appropriate for grasping the complex interactions that occur during function (Smith 1992, Thiele et al. 1992).

A noninvasive, objective study of muscle function is possible, however, with the aid of electromagnetic articulography (Ackermann et al. 1993, Engelke et al. 1990).

106 Anatomical preparation of the left buccinator muscle
This muscle (1) determines the transverse position of the posterior teeth in the dental arch by countering the pressure of the tongue. During chewing, the buccinators and the tongue work together to keep the food between the occlusal surfaces. In playing a wind instrument, each buccinator (Latin for *trumpeter)* supports the stream of air laterally. Their hyperfunction causes a narrowing of the upper and lower jaws with the formation of an exaggerated linea alba inside the cheeks.

From the collection of B. Tillmann



107 Orbicularis oris muscle
The orbicularis oris is the muscular foundation of the lips (Thiele et al. 1992). It is made up of a pars marginalis, pars labialis, and a system of straight radiating muscles. Strictly speaking, it consists of two arches that are connected by fascia at the corners of the mouth. Hypertonus results in a small, sharp mouth. The orbicularis oris in combination with interwoven surrounding muscles can position the lower lip between the incisors and cause an anterior horizontal overlap ("overjet").

108 Mentalis muscle
Right: Frontal view of a patient with a hyperactive mentalis muscle. The muscle is the cause of the forceful lip closure. With hyperactivity the lower lip presses in on the lower incisors and the upper lip can be forced upward. This can result in a reduction of lip pressure against the upper incisors.

Left: Same patient in profile view. Because of the hypertonic mentalis, the apex of the chin (pogonion) lies well in front of the alveolar process.

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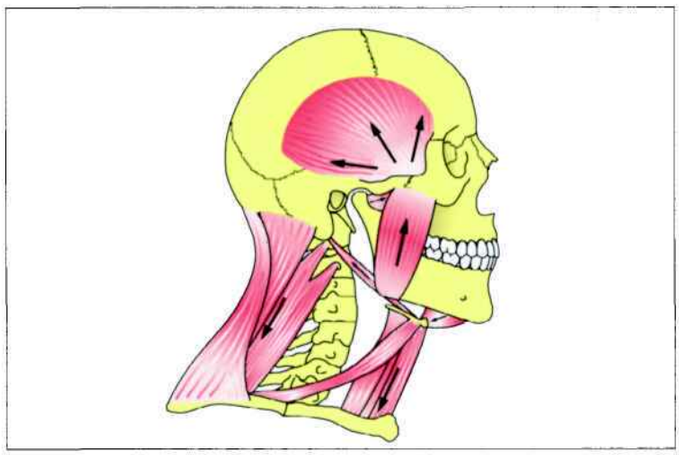
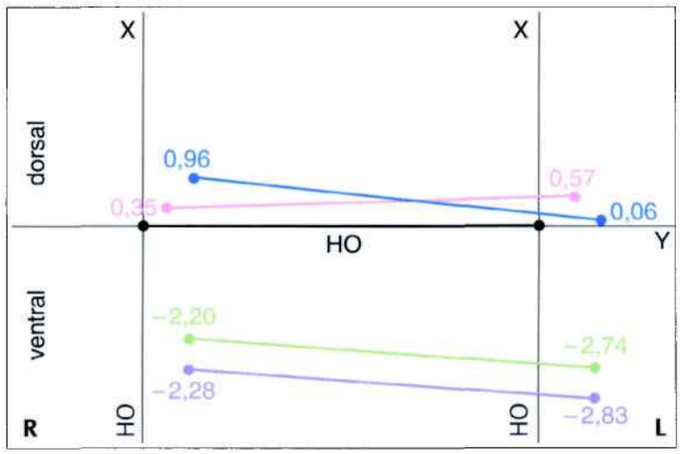
Temporomandibular Joint and the Musculoskeletal System

The relationships between functional disturbances of the temporomandibular joint and the rest of the musculoskeletal system are well known from clinical investigations (Smith 1993, de Wijer et al. 1996b,c, Dvorak and Walchli 1997). The structural and neurophysiological connections, however, are subjects of debate (Graf-Baumann and Lohse-Busch 1997). Head and neck pain, referred pain, pain in the area innervated by the trigeminal nerve, and disturbances in the functions of speech and swallowing are often associated with the upper cervical spine (Wolff 1996). Disturbances in the cervical vertebrae C2 and C3 can bring on dysphonia and the sensation of a lump in the throat. Up to 25% of patients with temporomandibular-joint disturbances report tinnitus (Hülse 1998), whereas 16% of all adults in our industrial society have a long-standing history of ear noises. Lotzmann and Steinberg (1993) demonstrated changes in body posture after removal of premature tooth contacts. On the other hand, artificial alterations of the occlusion in healthy test subjects had no effect on body posture (Ferrario et al. 1996a).

109 Influence of head and body posture on the mandible
Schematic drawing showing the muscular suspension of the mandible and its relation to the muscles of the neck. As an example, the sternocleidomastoid muscle is always active during bruxism; however, an activity level of 50% is necessary in the masseter muscle before a 5% level is reached in the sternocleidomastoid muscle (Clark et al. 1993).

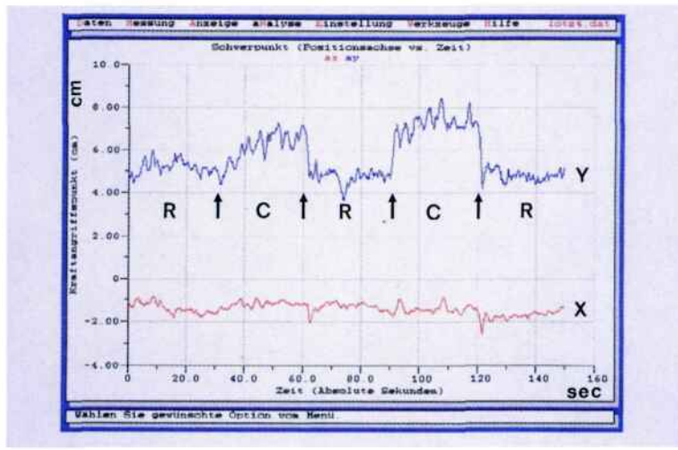


110 Influence of a functional disturbance in the cervical spinal column upon centric position
Changes in condylar position in the horizontal plane following isolated orthopedic treatment of the upper cervical spinal column.
Red: Initial findings
Blue: Control findings after 6 weeks with no treatment
Lilac: Findings after 3 weeks of treatment
Green: Control findings after 3 months
In each group the difference from habitual occlusion (HO) is given in millimeters.



111 Influence of the occlusion upon body posture
Left: Recording of changes in the upright body posture (orthostasis). In this case voluntary clenching on an unstable occlusion resulted in a repeatable posterior shift in the body's center of gravity.

Right: Clinical arrangement with the patient on the measuring platform that detects even minor changes in the patient's center of gravity projected horizontally.



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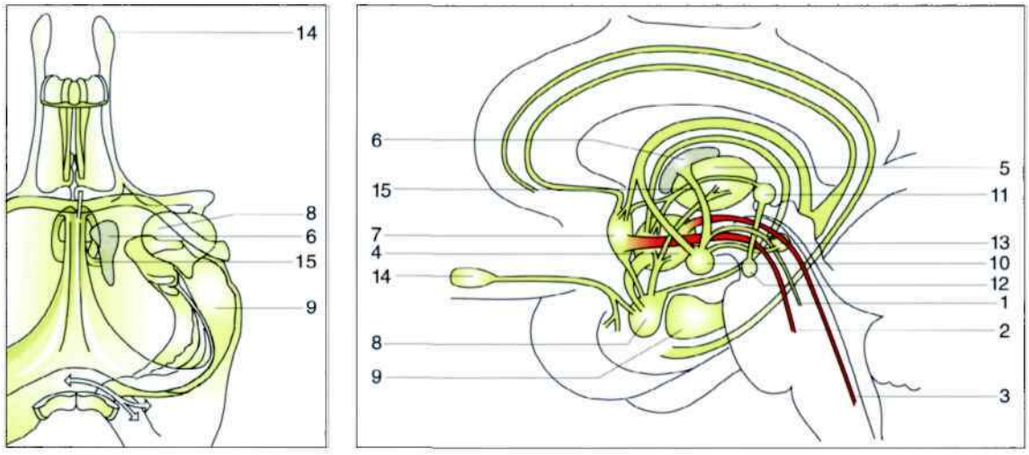
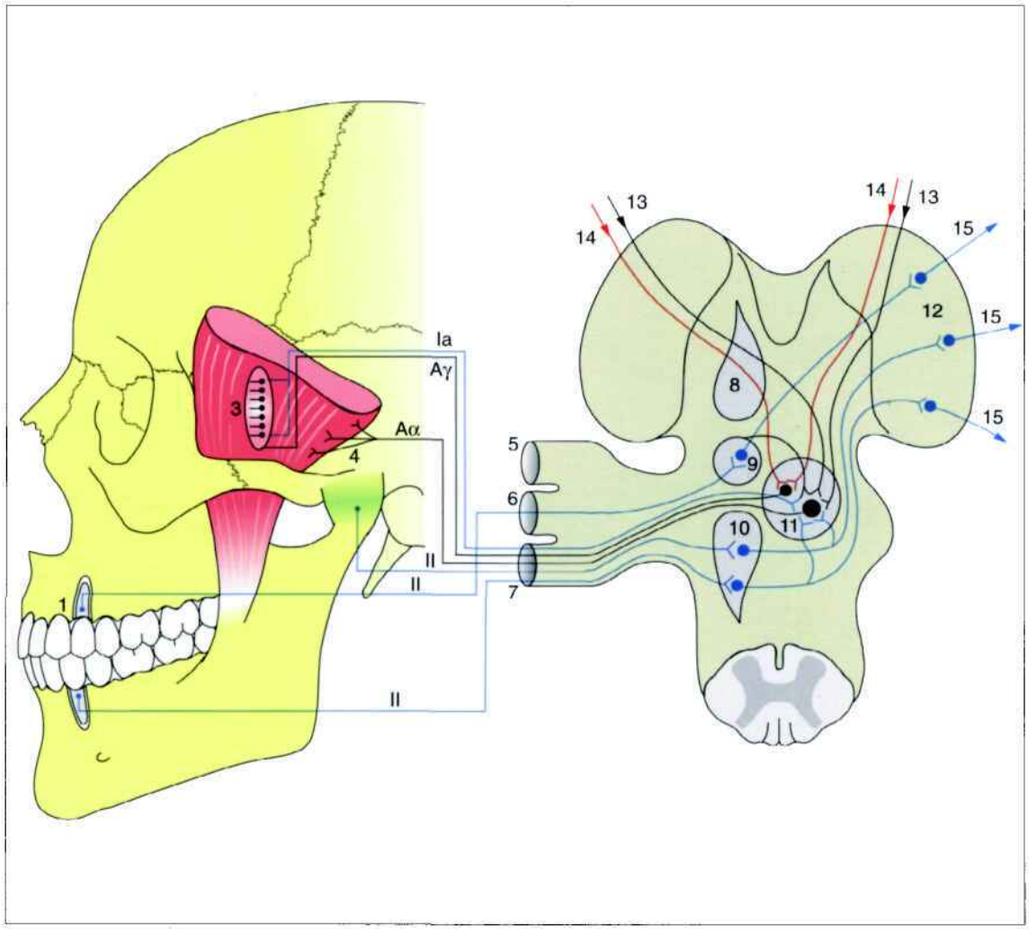
Peripheral and Central Control of Muscle Tonus

Muscle spindles and Golgi tendon organs are the two types of receptors in muscles that are involved in controlling muscle activity. Peripheral monitoring occurs primarily through the monosynaptic proprioceptive reflex and the polysynaptic stretch reflex (Guyton and Hall 1996). Increases in length are reported from the muscle spindles over Ia fibers directly to the corresponding α-motoneuron and can then be corrected (phasic proprioceptive reflex). Golgi receptors read the muscle force and transmit this information over Ib fibers to an inhibitory intermediate neuron. This again inhibits the α-motoneurons (Johnson 1998). The resting tonus is a continuous background level of contraction that is maintained primarily through a segmental spinal reflex (Graber 1989). Supraspinal centers can both inhibit and promote muscle tone. Here the limbic system plays an essential role. It is the complex circuitry of numerous pathways and nuclei that make it possible for individuals to control their emotions and behavior. Muscle tone is influenced predominantly by the γ-motoneurons (Johnson 1998).



112 Limbic system
After Nieuwenhuys et al. 7980.

1 Mamillotegmental tract
2 Fasciculus telencephalicus med.
3 Inferior longitudinal fasciculus
4 Hypothalamus
5 Nucleus medialis dorsalis thalami
6 Anterior thalamic nucleus
7 Septal area
8 Amygdaloid body
9 Hippocampus formation
10 Mamillary body
11 Habenula
12 Ncl. Interpendicularis
13 Dorsal tegmental nucleus
14 Olfactory bulb
15 Mamiltothalamic tract



113 Central and peripheral neuromuscular control
Muscle activity can be influenced by both peripheral and central nerves. Emotional factors increase muscle tonus through γ-neurons.

1 Periodontal receptors
2 Joint capsule receptors
3 Muscle spindles (stretching)
4 Motor end plates
5 Trigeminal nerve (semilunar ganglion)
6 Trigeminal nerve (semilunar ganglion)
7 Trigeminal nerve (semilunar ganglion)
8 Mesencephalic tract nucleus
9 Superior sensory nucleus (n.V)
10 Inferior sensory nucleus (n. V)
11 Motor nucleus (n. V)
12 Thalamus
13 Descending paths from cortex (α-motor = "voluntary motor")
14 Descending paths from limbic system (γ-motor = "psychovegetative impulses"
15 Ascending paths to cortex ("consciousness")

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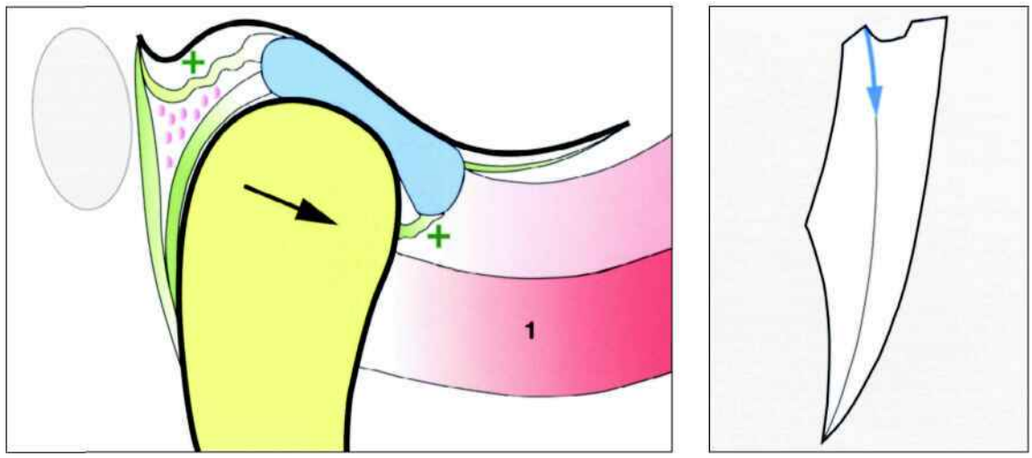
Physiology of the Jaw-Opening Movement

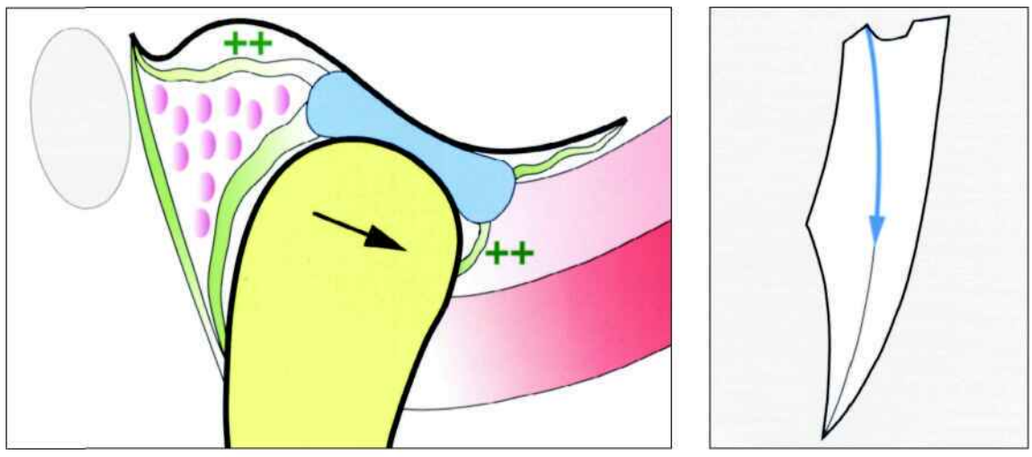
Jaw opening is accomplished through the action of the suprahyoid muscles (rotation) and the lateral pterygoid muscles (translation). In centric condylar position the elastic fibers in the temporomandibular joint are in equilibrium. The initial phase of an opening movement is primarily a rotation that always progresses with a translational component (Merlini and Palla 1988, Maeda et al. 1992, Ferrario et al. 1996a). The opening rotation of the condyle always causes the disk to lie against a more posterior region of the condyle where it is more stable. During translation the disk is passively carried along in an anterior direction (Sicher 1964, Roth et al. 1984, Osborn 1985). During jaw opening, tension increases in the superior stratum and in the lower anterior wall of the joint capsule. While the superior stratum can restrict anterior movement of the disk (Dauber 1987), it cannot restrict jaw opening. This is limited by the joint capsule and the lateral ligament. During jaw opening the genu vasculosum expands to approximately four or five times its original volume (Rees 1954, Wilkinson et al. 1994), so that during excursions a negative pressure arises within it (Finlay 1964, Ward et al. 1990).

Jaw-opening movements

114 Initial phase
Illustration of the structural loading during the initial opening movement. The condyle makes a rotational movement with a small translational component, changing its position relative to the fossa only slightly. Because of the condylar rotation, the disk moves posteriorly relative to the condyle. The only part of the lateral pterygoid muscle that is active is its lower head (1). The elastic fibers are brought out of equilibrium only minimally.

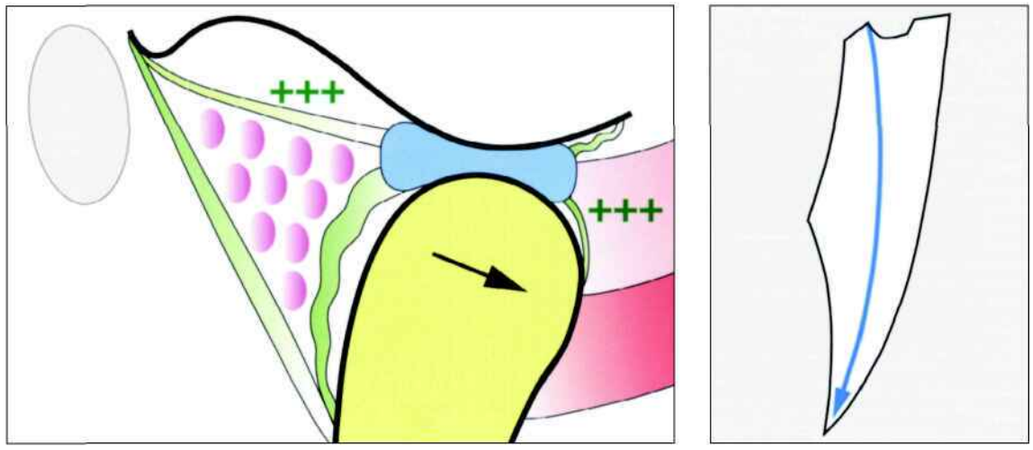


115 Intermediate phase
In this phase the condyle executes a definite translation. The disk moves anteriorly relative to the fossa, but posteriorly in relation to the condyle. Tension becomes steadily increased in the superior stratum of the bilaminar zone and in the lower anterior wall of the joint capsule. The inferior stratum relaxes to the same extent. The venous plexus of the genu vasculosum expands, creating a negative pressure, and fills with blood.



116 Terminal phase
In this phase the condyle reaches the maximum extent of its rotation and translation. The translational component passively moves the disk farther forward, while the rotation makes it lie farther posteriorly on the condyle. The superior stratum and the lower anterior capsule wall are now stretched to their maximum. The retrocondylar space is filled by the blood flowing into the genu vasculosum. The inferior stratum is completely relaxed.

Right: Degree of opening in Posselt's envelope of motion.



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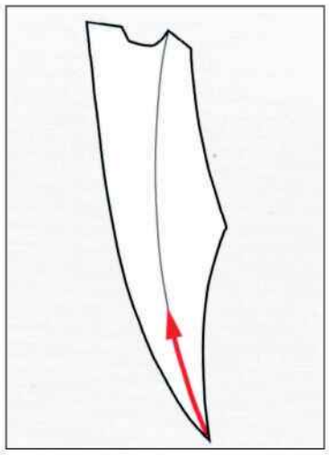
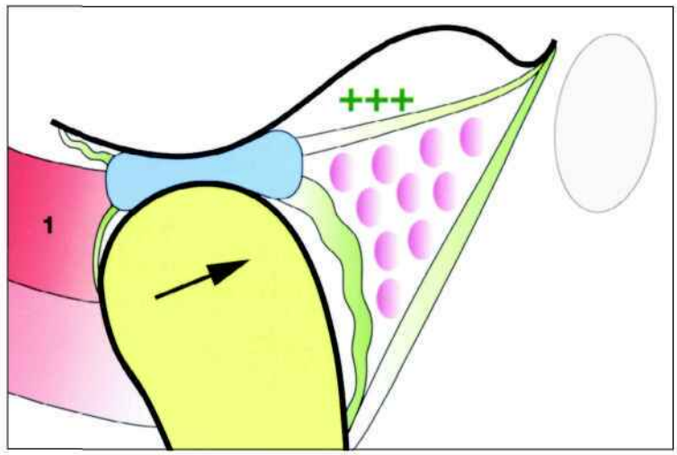
Physiology of the Jaw-Closing Movement

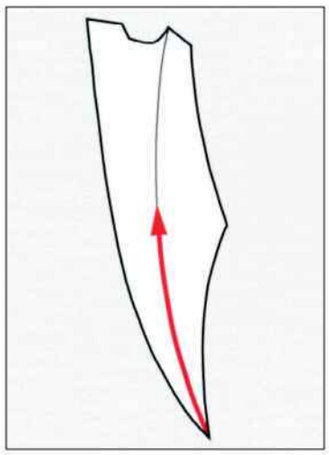
The jaw is closed by the temporal, masseter, and medial pterygoid muscles and the upper heads of the lateral pterygoid muscles. The lower head of the lateral pterygoid muscle is inactive during jaw closure. As described previously, the temporal and masseter muscles also insert on the anterior part of the joint capsule. This maintains the basic level of tension necessary for the receptors in the joint capsule to function. It is a fundamental fact that during closing movements the disk executes an anterior movement relative to the condyle. As the condyle is being drawn posteriorly by the muscles, other structures are guiding the disk posteriorly and preventing its anterior displacement at the end of the closing movement. The elastic superior stratum is responsible for moving the articular disk back during the initial phase of closure (Ries 1954, Dauber 1987). In the intermediate phase the disk, because of the convexity of its pars posterior, is carried along passively with the condyle in a posterior direction (Carpentier et al. 1988). During the final closing rotation the taut inferior stratum holds the disk on the condyle (Carpentier et al. 1988, Luder and Bobst 1991).

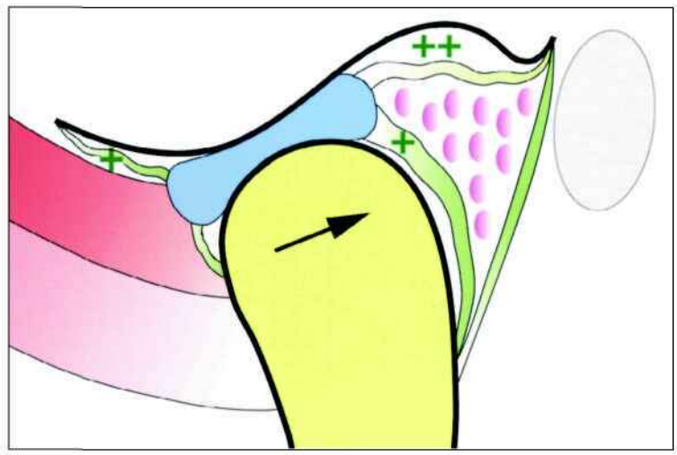




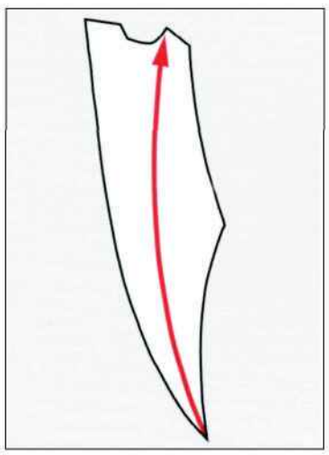
Jaw-closing movement

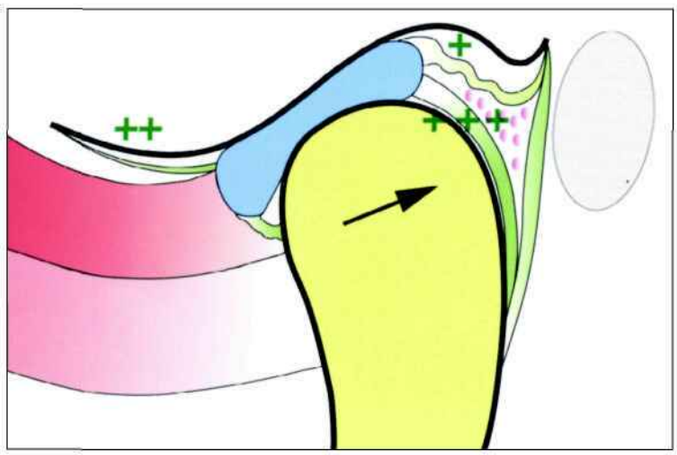
117 Initial phase
Schematic representation of the structural loading during the initial jaw-closing movement. The upper head (1) of the lateral pterygoid muscle retards distal movement of the condyle through eccentric muscle activity. The disk can only be passively guided posteriorly. In the initial phase this is brought about by the tension in the elastic superior stratum. A physiological positive pressure arises in the genu vasculosum (Finlay 1964, Ward et al. 1990).





118 Intermediate phase
In this phase the upper head further stabilizes the condyle on the articular protuberance. Tension in the superior stratum steadily diminishes, and the disk, because of the bulge of its pars posterior, is passively carried farther distally. A nonphysiological increase of pressure in the genu vasculosum due to sympathetic or hormonal influences would exert an anteriorly directed force on the disk (Ward et al. 1990). This can lead to increased tension in the inferior stratum and flattening of the disk.





119 Terminal phase
Once the jaws are closed the elastic structures are again relaxed. The inferior stratum becomes increasingly tense and finally prevents anterior disk displacement in case the condyle moves too far distally. Anterior disk displacement can occur only in the presence of an overstretched inferior stratum, with or without flattening of the pars posterior (Eriksson et al. 1992).

Left: Degree of closure in the Posselt diagram.

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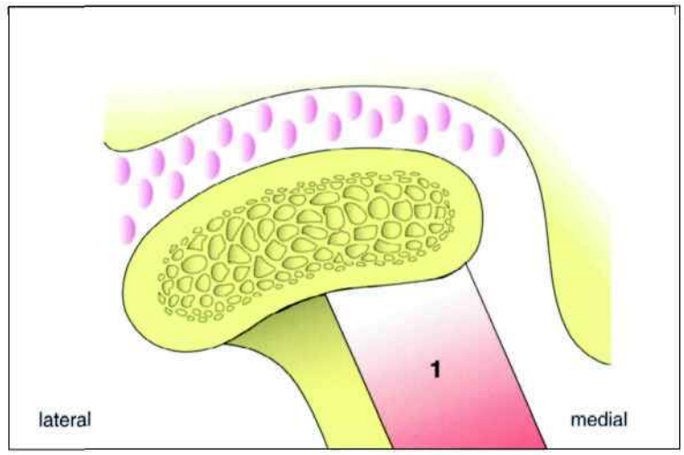
Physiology of Movements in the Horizontal Plane

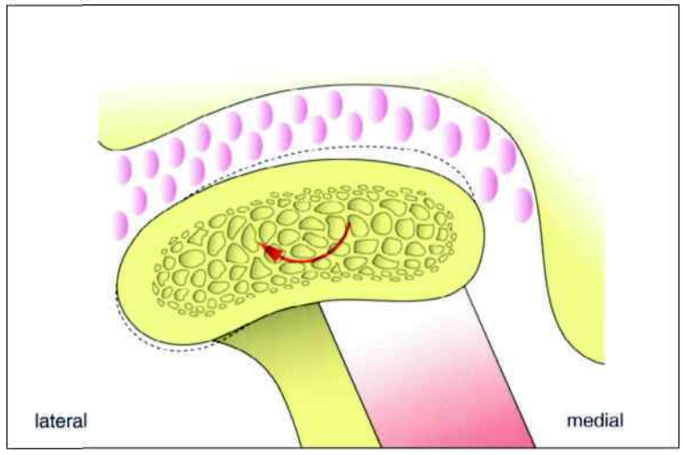
During lateral movements of the mandible, the condyle on the working side moves in laterotrusion and the condyle on the nonworking side in mediotrusion. In the centric condylar position all the structural components of the temporomandibular joint are in equilibrium and are not subjected to any nonphysiological loads. In the ideal situation, the working condyle rotates around a vertical axis during laterotrusion. The condylar position can then be stabilized by either muscles or ligaments. If the laterotrusion is stabilized by the lateral pterygoid muscle, the center of rotation will lie more medial within the condyle. If, on the other hand, stabilization is ligamentary, the center of rotation will lie more in the lateral portion because of the insertion of the lateral ligament. A lateroretrusion of the condyle is possible only if the lateral ligament is overstretched. In this case the posterolateral part of the condyle would compromise the bilaminar zone but the joint surfaces would be relieved of pressure.

During *mediotrusion* the corresponding condyle moves anteriorly, inferiorly, and medially. This causes loading of the joint surfaces and the capsule and unloading of the bilaminar zone.

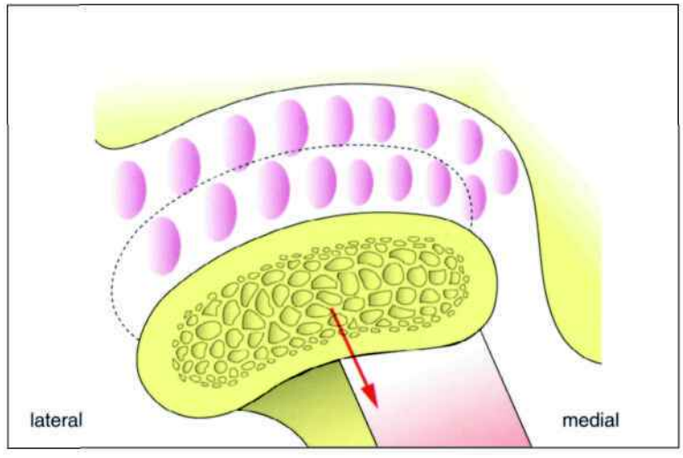
120 Centric condylar position
Schematic drawing of the position of a right condyle in relation to the posterior and medial borders of the bony fossa in the horizontal plane. At this level the lower head (1) of the lateral pterygoid muscle inserts on the anteromedial surface of the condyle. In centric condylar position the bilaminar zone and the genu vasculosum (lilac colored) are not overloaded. Transverse movements can amount to 0.9 mm in the working condyle and 0.4 mm in the balancing condyle (Lückerath and Helfgen1991).



121 Laterotrusion in the horizontal plane
Position of a right condyle relative to the posterior and medial borders of the bony fossa during laterotrusion. Ideally, the condyle would turn around a vertical axis running through the center of the condyle. But if the lateral ligament is overstretched, a lateroretrusion can also occur. In this case the lateral portion of the bilaminar zone and the genu vasculosum would become overloaded (Coffey et al. 1989).



122 Mediotrusion in the horizontal plane
Illustration of the position of a right condyle during a mediotrusive movement. The condyle moves forward, medially, and downward. The entire genu vasculosum is relieved of pressure and the lateral part of the superior stratum becomes stretched more than the medial part. Correspondingly, most of the elastic fibers seen histologically are in its posterolateral region. The result of overloading of the medial portion of the bilaminar zone will always be traumatic rather than functional.



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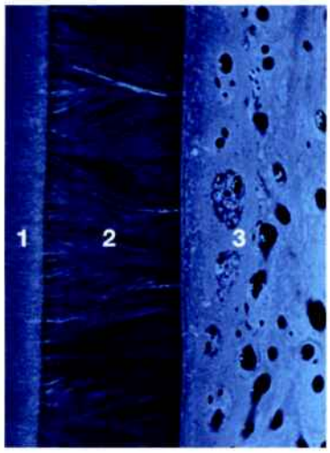
The Teeth and Periodontal Receptors

The periodontium is innervated by both myelinated and unmyelinated nerve fibers. The receptors can be divided into type I (mechanoreceptors) and type II (nociceptors) (Griffin and Harris 1974) and are analogous to the "Ruffini type" (Linden and Millar 1988a, Sato et al. 1992), although other forms also appear (Lambrichts et al. 1992, Fukuda and Tazaki 1994). The cell nuclei of the mechanoreceptors are found either in the trigeminal ganglion or in the mesencephalic nucleus of the trigeminal nerve. Receptor cells with their nuclei in the mesencephalic nucleus (high threshold, rapid adaptation) are located predominantly at the root apices, while receptors with their nuclei in the ganglion (low threshold, slow adaptation) are more numerous around the root, especially in the middle third (Byers and Dong 1989). The afferent nerves are made up of Aβ fibers for mechanoreception and A6 fibers and C fibers for pain perception (Mengel et al. 1993, Linden et al. 1994).

Approximately 50% of the afferent nerves also react to stimuli acting on adjoining teeth (Trulsson 1993, Tabata et al. 1995). Therefore, there is no neurophysiological difference between canine guidance and group function.



123 Healthy dentition
Left: Microscopic view of the histology of a periodontal space: cementum (1), collagen fibers (2), alveolar bone (3).

Right: Simultaneous tooth contact is the foundation for neuromuscular guidance. The mechanoceceptors in the periodontium react most to lingual loading of the tooth (Trulsson et al. 1992). The reaction and adaptation of a mechanoreceptor depends, among other things, upon the speed of the mechanical stimulus (Linden and Millar 1988b, Linden et al. 1994, Millar et al. 1989).

124 Incisors, premolars, molars
Left: Relation of the incisors in protrusive position. The periodontal membranes of the incisors have the highest concentration of mechanoreceptors. Furthermore, their threshold of stimulation is significantly lower than that of the molars.

Center: Extensive abrasion is not necessarily indicative of occlusal trauma (Green and Levine 1996).

Right: Apparently intact occlusal surfaces are no guarantee of physiological tooth loading.

125 Excessive attrition
Advanced attrition can result in specific changes in the distribution and micromorphology of the mechanoreceptors (Sodeyama et al. 1996) and suppress the guiding and protective mechanisms of periodontal perception.

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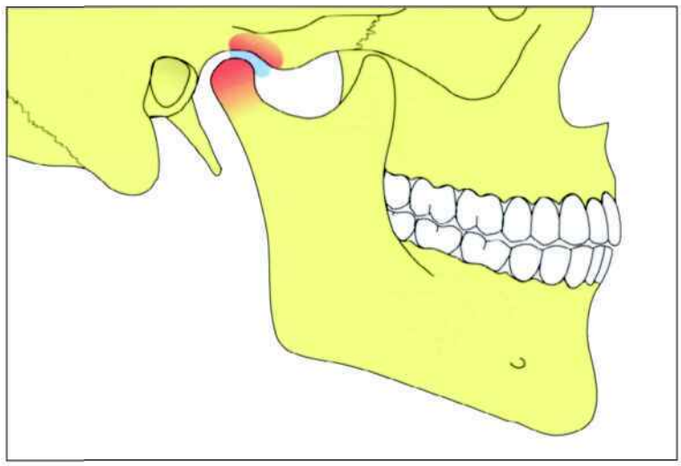
Condylar Positions

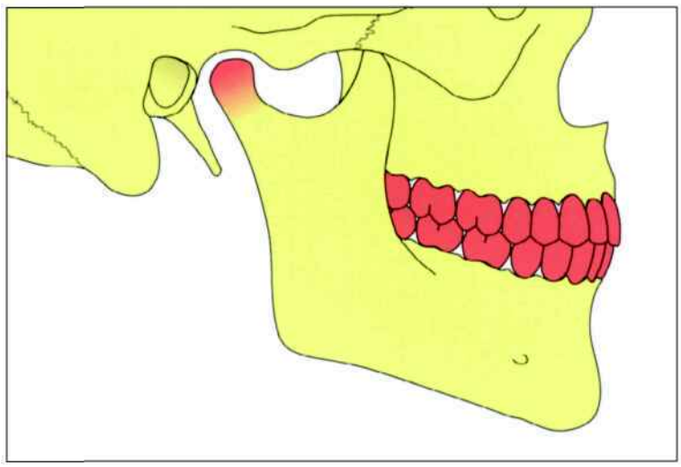
The centric condylar position has been a subject of controversy in dentistry for many decades. However, if one considers mainly the anatomical and neurophysiological fundamentals and relegates the artificial, mechanistic concept of a rigid, unalterable condylar position to the background, the problem becomes less confusing. According to our current state of knowledge, four basic condylar positions can be distinguished: centric, habitual, therapeutic, and adapted. Of these, only the centric condylar position is not necessarily dictated by the occlusion.

Centric condylar position describes the ideal arrangement of a temporomandibular joint (van Blarcom 1994, Lotzmann 1999). Because many deviations from this ideal condition are seen in everyday practice, Dawson (1995) introduced the term *adapted condylar position.* This applies to all fossa-disk-condyle relationships that deviate from the ideal norm within the individual's range of adaptation, These condylar positions are the ones most frequently encountered. The habitual and therapeutic condylar positions will be discussed in more detail in later chapters.

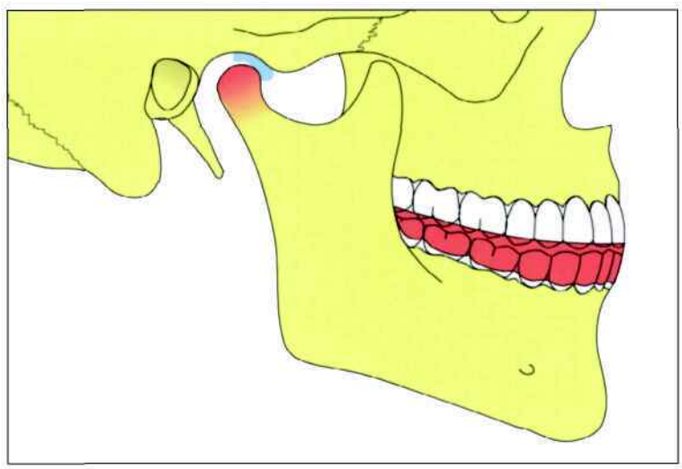
126 Centric condylar position
This is defined as the anterosuperior position of both condyles in a physiological condyle-disk relationship with no lateral shift and physiological loading of the involved tissues. The centric condylar position is totally independent of the occlusion of the patient's teeth. Therefore it can be determined clinically only while there is no tooth contact. Correct anterosuperior positioning of the condyles is achieved only through the patient's neuromuscular system. Any manipulation will produce a deviation.



127 Habitual condylar position
This is the position usually assumed by the condyle on the articular eminence. The habitual condylar position is determined exclusively by the patient's static occlusion with no influence from the fossa or the position of the disk. In an ideal case, the habitual condylar position would coincide with the centric condylar position. For its clinical determination and its differentiation from the adapted condylar position, see pages 125ff and 206ff.



128 Therapeutic condylar position
The therapeutic condylar position is a position selected arbitrarily by the dentist to correct a problem. The purpose may be to re-establish the functional unity of an anteriorly displaced disk and its condyle or to temporarily relieve the pressure on the bilaminar zone within an inflammed capsule. Usually this is accomplished by inserting a splint with indentations for the opposing molar cusps and retrusion planes in the premolar and canine regions.



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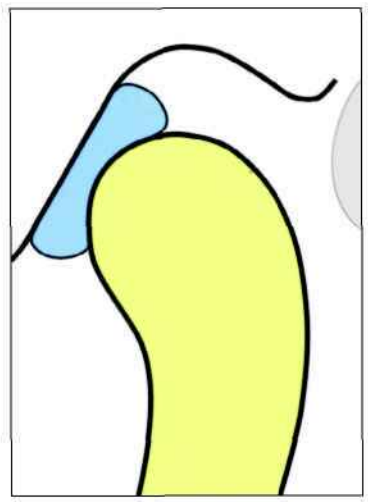
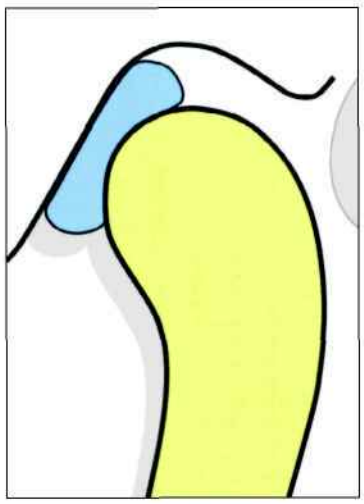
Static Occlusion

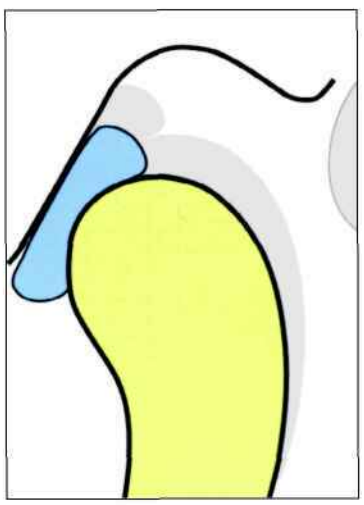
Because the condylar positions are primarily independent of the occlusion, there are analogous definitions for the corresponding tooth contacts. *Occlusion* itself is defined as "every contact of teeth of the maxilla with those of the mandible" (van Blarcom 1994, Lotzmann 1999). Static occlusion means tooth contact with no movement of the mandible. Static occlusions can be divided into centric, habitual, and maximal occlusion. *Centric* occlusion is defined as those tooth contacts that occur with the condyles in centric condylar position. The term can apply to one single contact (premature contact) or maximum contact at many points. *Habitual* occlusion is the static occlusion the patient usually assumes. It determines the habitual condylar position. In some cases the habitual occlusion may be the same as centric occlusion. In this situation the habitual condylar position would likewise be the same as the centric condylar position. *Maximal* occlusion describes a static occlusion in which there is the maximum number of contacts. The number of contacts aimed for in treatment depends upon which concept of occlusion is utilized.



129 Centric occlusion
The traditional definition of centric occlusion has been expanded to include not only maximum intercuspation, but also any tooth contacts that the patient can make with the condyles in centric position (left).



130 Habitual occlusion
This indicates the most commonly assumed tooth contacts. These can be many or, with a malocclusion, few. Habitual occlusion determines the habitual condylar position. With the teeth in habitual occlusion the condyles may be displaced in the sagittal plane either posteriorly (yellow) or anteriorly (gray) from the centric condylar position. Lateral displacement is also possible. All the joint structures may adapt successfully to this condition.



131 Maximal occlusion
This describes the presence of a maximum number of contact points. The concept of maximal occlusion is not dependent upon the position of the condyles. Closing into maximal occlusion may displace the condyles along any of the three spatial coordinates. Ideally, however, maximal occlusion would occur simultaneously with centric condylar position (gray). There is no compelling medical reason to treat a condylar shift in maximal occlusion if the joint structures are well adapted.

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Dynamic Occlusion

The term *"dynamic occlusion"* covers all tooth contacts that occur during movements of the mandible (Lotzmann 1981, van Blarcom 1994). The term "*articulation*" is now obsolete. There are three important concepts for eccentric occlusion:

- Anterior/canine protected occlusion: The incisors and canines provide disclusion of all other teeth. Anterior/canine guidance is the occlusal concept most easily achieved clinically and in the laboratory.
- Unilateral balanced occlusion (group function): guidance on all the teeth of the laterotrusive side with disclusion of the opposite side.

The majority of young adults exhibit a more or less unilaterally balanced occlusion. About half of them, however, make balancing contacts on the nonworking side after a laterotrusive movement of 1.5 mm. In another third, balancing contacts are present after an excursion of 3 mm (Ingervallet al. 1991).

- Bilateral balanced occlusion: all teeth remain in contact during laterotrusion.

The bilateral balanced occlusion is difficult to achieve in the natural dentition. Nevertheless, balancing contacts can offer protection for the joints in some cases.

132 Canine guidance
With canine guidance, not only should all the other teeth disclude (vertical disclusion), but only the distal slope of the lower canine should slide against the mesial slope of the upper canine. This arrangement also provides a so-called "sagittal protection." This is important from a prophylactic standpoint because it helps keep the condyle from impinging upon the sensitive bilaminar zone during lateral movements (see p. 48).

133 Croup function (unilateral balanced occlusion)
Group function involves multiple teeth on the laterotrusive (working) side including the canines, premolars, and sometimes also the molars. There are no contacts on the contralateral (nonworking) side during the lateral movement.
Clinically, patients find a moderate canine guidance to be the most comfortable. Surprisingly, this does not correlate with the measured EMG activity of the muscles of mastication (Soneda 1989).

134 Balancing contact
Canine guidance on the laterotrusive side during right lateral movement of the mandible.

Right: Simultaneous tooth contacts on the contralateral side are referred to as balancing contacts. If the contralateral contacts hinder guidance on the laterotrusive side, they are called hyperbalancing contacts, or nonworking interferences. In specific functional disturbances balancing contacts can be advantageous to treatment (see p. 318).

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Manual Functional Analysis

Manual examination techniques for systematic testing of the musculoskeletal system can be traced back to the London orthopedist Cyriax. His 1933 textbook describes specific techniques for examining the temporomandibular joint. During recent decades, conventional functional diagnostics in dentistry was based primarily upon the study of active movements and muscle palpation (Dworkin et al. 1988, Fuhr and Reiber 1989, Siebert 1996). The system used was derived mostly from the examination techniques of Krogh-Poulsen (1966). Hansson et al. (1980, 1987) were the first to advocate applying the examination methods from orthopedics and manipulative therapy (Cyriax 1947; Mennell 1949; Maitland 1964; Wolff 1970; Mennell 1970, 1978; Kaltenborn 1976L; Cyriax 1947, 1979; Frisch 1987) to examination of the temporomandibular joint.

Over the years many other authors adopted various orthopedic tests and described their diagnostic potential (Friedman and Weisberg 1982, 1984; Palla 1986; Solberg 1986; McCarroll et al. 1987; Roller 1989; Hesse et al. 1990; Steenks and de Wijer 1991; De Laat et al. 1993; Lobbezoo-Scholte et al. 1993, 1994; Hesse 1996; Hesse et al. 1996, 1997).

By itself, however, the application of the "new" examination techniques to complement the conventional evaluation of active movements and muscle palpations still did not represent a decisive advance in clinical functional diagnostics.

The multitude of examination techniques available were taken up in 1988 by G. Groot Landeweer and A. Bumann and further developed into a systematic, practice-oriented examination concept. The term *manual functional analysis* was introduced to describe the new concept (Groot Landeweer and Bumann 1991, Bumann et al. 1993, Bumann and Schwarzer 1995, Bumann and Groot Landeweer 1996a, b) and to differentiate it from *instrumented functional diagnostics*, which was highly rated at that time, and from the term *clinical functional analysis,* which was used for the conventional procedures.

After a few years of intensive clinical experience, the initial concept (Groot Landeweer and Bumann 1992, Bumann and Groot Landeweer 1992) of the basic examination and the expanded examination—associated with the spiritual father of manipulative medicine—was abandoned in favor of a systematic, goal-oriented testing of the individual anatomical structures (joint surfaces, bilaminar zone, capsule and ligaments, muscles of mastication). In addition, specific techniques for differentiating various clicking phenomena in the human temporomandibular joint were described (Bumann and Groot Landeweer 1993), and the reliability of these for diagnosing partial and total disk displacements was demonstrated (Bumann and Zaboulas 1996).

The introduction of the so-called *loading vector* represents a major advance in manual functional analysis. This describes the direction of any load that is responsible for an area of tissue damage within the joint and provides a better understanding of malfunctions of the system. A determination of the specific loading vector is important if one is to follow an effective procedure for arriving at a diagnosis and treatment plan. Therefore the current concept of manual functional analysis takes the following aspects into consideration:

- A search for the loading vector at any given time
- Tests for any possible restrictions to movement
- Determination of various harmful influences

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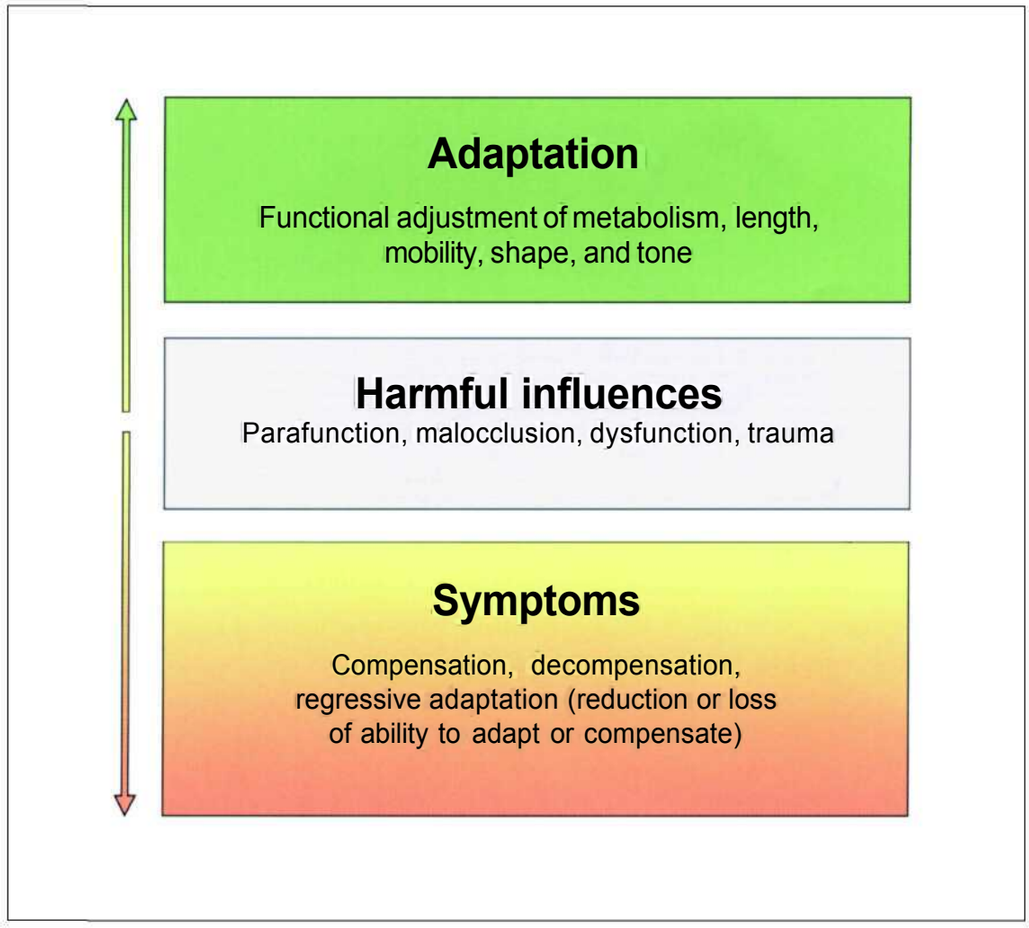
The Masticatory System as a Biological System

The introduction contains a brief discussion on how influences, mechanisms of adaptation and compensation, and the emergence of symptoms are interrelated. Whether or not symptoms will arise in the masticatory system depends primarily on the equilibrium between the harmful influences and the patient's capacity for adaptation. The resultant influence is a combination of the number, duration, amplitude, and frequency of all the individual influences (static and dynamic occlusion, parafunctions, and dysfunctions). The dentist can alter this equilibrium only to a very limited extent. Because the patient's individual adaptability cannot be influenced directly, one who treats a biological system such as the masticatory system can only indirectly help the organism to adapt by reducing the sum total of the harmful influences. For the dentist, this means that he/she can bring about a positive influence on a disrupted functional system only if the functional disturbance is at least partially the result of a nonphysiological static and/or dynamic occlusion,

135 Biological systems
Influences within biological systems are processed through two mechanisms. When a system has the ability to assimilate the acting stimulus passively without a further increase of its inherent energy, an adaptive condition exists. The second mechanism is compensation, in which there is an increase of the system's inherent energy with either an absence or a decrease in adaptation. With persisting unphysiological loading the system can lose its ability to compensate (decompensation) and undergoes collapse, usually with the appearance of clinical symptoms.
It is essential during examination of the masticatory system that the clinician is able to differentiate between these two conditions, adaptation on the one hand and and loss of adaptation or loss of compensation on the other. Systems that are in an adaptive state require no treatment. When adaptation becomes lost, treatment is necessary; the treatment goal is the restoration of an adapted condition.



The first part of the manual functional analysis procedure determines the patient's complaints and the degree of damage of the relevant tissue. The principle of the examination is similar to that of a stress EKG: the structures of the masticatory system are loaded to the maximum in a specified sequence. A patient may react to this in one of three ways:

- The stress on the tissue provokes no pain or other symptoms. This is a *physiological response* and is a sign that the structures are either unaltered or *optimally adapted.*

- In the second type of response, symptoms are brought forth only during application of the stress and are therefore not experienced during the patient's normal activities. This condition is referred to as a *compensated* /unc- *tional disturbance.*

- The third possibility is the reproducible provocation of the same symptoms that brought the patient to the clinician and which were reported in the patient history. This indicates the presence of *a decompensated or regressively adapted functional disturbance.* It is caused either by overloading of a muscle (decompensation), traumatic tissue damage, or, most commonly, by inflammatory tissue destruction (regressive adaptation),

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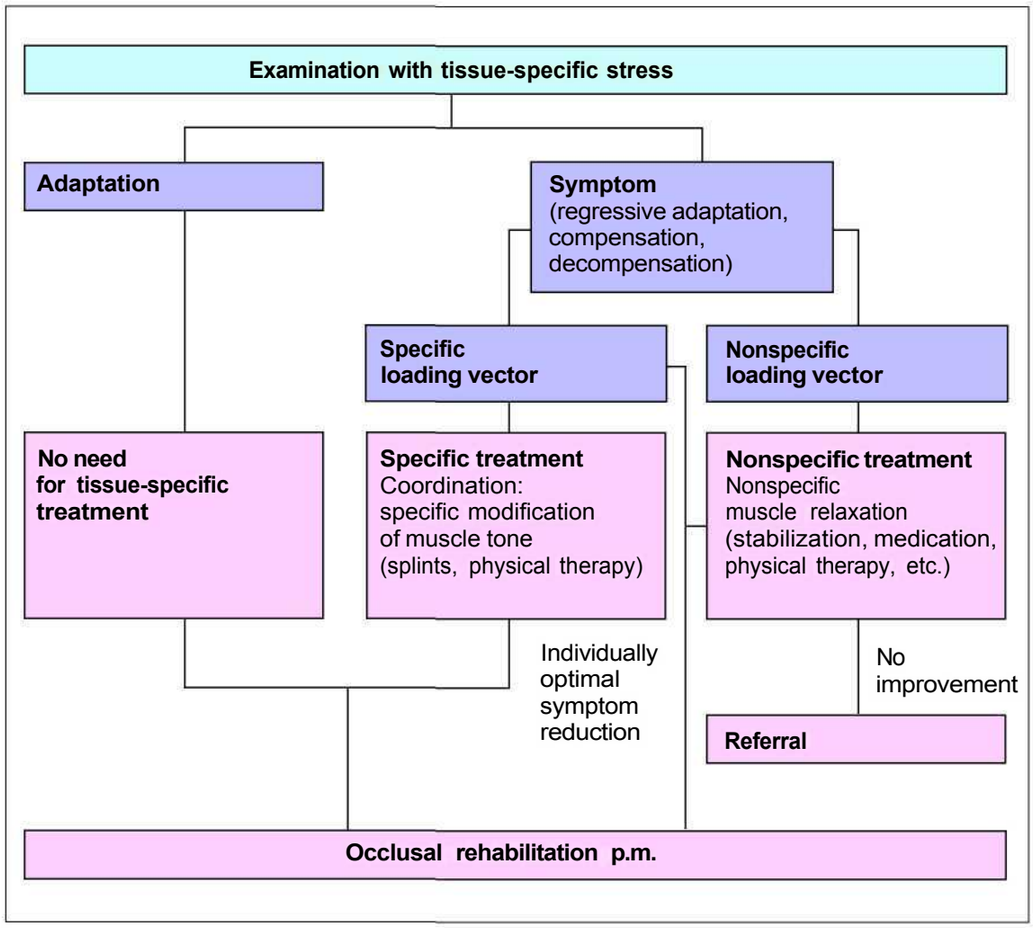
Specific and Nonspecific Loading Vectors

As soon as clinically reproducible symptoms are provoked by manipulation, the examiner knows that a functional disturbance is present that may be either compensated, decompensated, or regressively adapted. In any biological system, functional symptoms are caused by chronic nonphysiological loading. Therefore, for the sake of treatment, it is important for the therapist to know the direction of the overloading. A nonphysiological load of a certain amount in a certain direction is called a *loading vector*. This may be specific or nonspecific.

A *specific* loading vector is present if symptoms appear only in one main direction during the tissue-specific examination. If, however, symptoms can be provoked in various directions, or even to some extent in opposite directions, then one is dealing with a *nonspecific* loading vector. In this case the second part of manual functional analysis, the specific clarification of the influences, would be nonproductive and should not be continued because of the ubiquitous manifestations of inflammation,



136 Treatment paths
Diagram of treatment paths based upon the findings arrived at through manual functional analysis.
The musculoskeletal parts of the masticatory system are investigated by manipulative testing methods in which tissue-specific stress is applied to the structures being examined. This differentiates between adaptive and nonadaptive conditions. The latter (regressive adaptation, compensation, and decompensation) are then identified by the patient's response to the mechanical loading. In this way an injured structure can be located by means of tissue-specific stress in either a single (specific) or in multiple (nonspecific) loading directions.
Injuries with a nonspecific loading vector call for general, nonspecific muscle relaxation, while those with one specific loading vector require targeted neuromuscular deprogramming followed by occlusal reconstruction.

A patient with a nonspecific loading vector is first given only primary, nonspecific pain treatment by stabilizing the system with the aid of an occlusal splint fabricated at the least painful mandibular position, as determined by the patient, In some cases this is supplemented with analgesic and/or anti-inflammatory medication, and/or physical therapy, During this phase, physiotherapeutic measures can be effective only if there are joint-relaxing vectors present that are not painful. As a rule, this is not the case when nonspecific loading vectors are present. It is hoped that during the primary pain treatment phase the nonspecific loading vector will be converted into a specific loading vector or, better yet, completely eliminated.

With identification of a specific loading vector, "clarification of the influences" (static and dynamic occlusion, parafunction, dysfunction, trauma) is completed. Cause-directed occlusal treatment is possible only if static or dynamic occlusal influences can be demonstrated. This type of treatment almost always begins with an occlusal splint to eliminate the occlusion-related part of the overall loading vector, Depending upon the number of influences present, this measure may allow the previously damaged structures to become completely adapted or be transformed into a compensated status. If success cannot be attained, the patient should be referred to a specialist,

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Examination Form for Manual Functional Analysis

In the past, only information that had very limited relevance to treatment could be derived from the tests of active movements then used and the palpation of the muscles of mastication.

An examination procedure that goes back to Cyriax (1947, 1979), Kaltenborn (1974), Maitland (1964, 1967), and Mennell (1970) was first recommended for use in dentistry by Hansson et al. (1980). At the end of the 1980s with the perspective gained through more than 10 years of application, this procedure was modified, systematically expanded, and optimized with a view to increasing its clinical relevance.

The *front side* of the examination form we use contains, in addititon to the patient's clerical information and history, an overview of the current tissue-specific primary diagnosis (e.g. regressively adapted or decompensated functional disturbances) and secondary diagnosis (compensated functional disturbances) as well as their loading vectors and the individual harmful influences. This differentiation is important for treatment planning as well as for establishing the treatment goal for the patient. Furthermore it gives an overview of diagnostic procedures and specific musculoskeletal impediments in the direction of treatment.

Form for recording findings of manual functional analysis
While the front of the examination form summarizes the diagnostic and therapeutic information, the reverse side is reserved for only the individual findings of the tissue-specific examination.

137 Front side of form
This side provides an overview of the tissue-specific primary and secondary diagnoses, etiological factors (influences), further diagnostic measures, and treatment planning.

MANUAL FUNCTIONAL ANALYSIS

Date recorded:

History
Symptoms ☐ Pain ☐ Limitation of movement ☐ Clicking ☐ Occlusion

Order of symptoms (e.g. 1. pain left side, 2. clicking right side, 3. pain right side) _____

Patient's expectations _____

Tissue-specific primary diagnoses		Loading vector		Clinical influences							
				Stat. occl.		Dyn. occl.		Bruxism		Dysfunction	
Right	Left	Right	Left	Right	Left	Right	Left	Right	Left	Right	Left

Tissue-specific secondary diagnoses		Loading vector		Clinical influences							
				Stat. occl.		Dyn. occl.		Bruxism		Dysfunction	
Right	Left	Right	Left	Right	Left	Right	Left	Right	Left	Right	Left

Supplementary diagnostic measures

☐ MRI ☐ Lateral ceph ☐ Analysis of etiological factors ☐ _____
☐ CT ☐ Articulator adjustment ☐ Joint vibration analysis ☐ _____
☐ Panoramic X-ray ☐ Instrumental occlusal analysis ☐ Osteopathic examination

Initial dental therapy (Removal of occlusal influences) ☐ Causal ☐ Symptomatic

Purpose of splint
☐ Elimination of occlusal vectors
☐ Alteration of vertical dimension
☐ Alteration of anterior and canine guidance
☐ Protection of enamel
☐ Ventral positioning
☐ Condylar stabilization
☐ Unspecific muscle relaxation

Condylar position
☐ Neuromuscular centric
☐ Physician-determined position
☐ Patient-determined position

Occlusal splint design

Type of splint
☐ Upper splint
☐ Lower splint
☐ Disc repositioning device

Incisors
☐ Flat
☐ Impressions
☐ No contact

Canines
☐ Vertical disclusion
☐ Dorsal protection

Premolars / molars
☐ Flat
☐ Impressions
☐ No contact

Removal of local restrictions
☐ Traction / translation
☐ Static / dynamic muscle stretching
☐ Isometry / isotonia / muscle coordination
☐ Mobilization of suprahyoid structures
☐ Alteration of functional pattern

Removal of systemic influences / restrictions
☐ Manual therapy
☐ Osteopathy
☐ Homeopathy
☐ Acupuncture
☐ Psychotherapy

Definitive dental therapy (occlusal stabilization)
☐ Occlusal adjustment
☐ Prosthetics
☐ Orthodontics
☐ Orthognathic surgery
☐ Lavage / TMJ surgery

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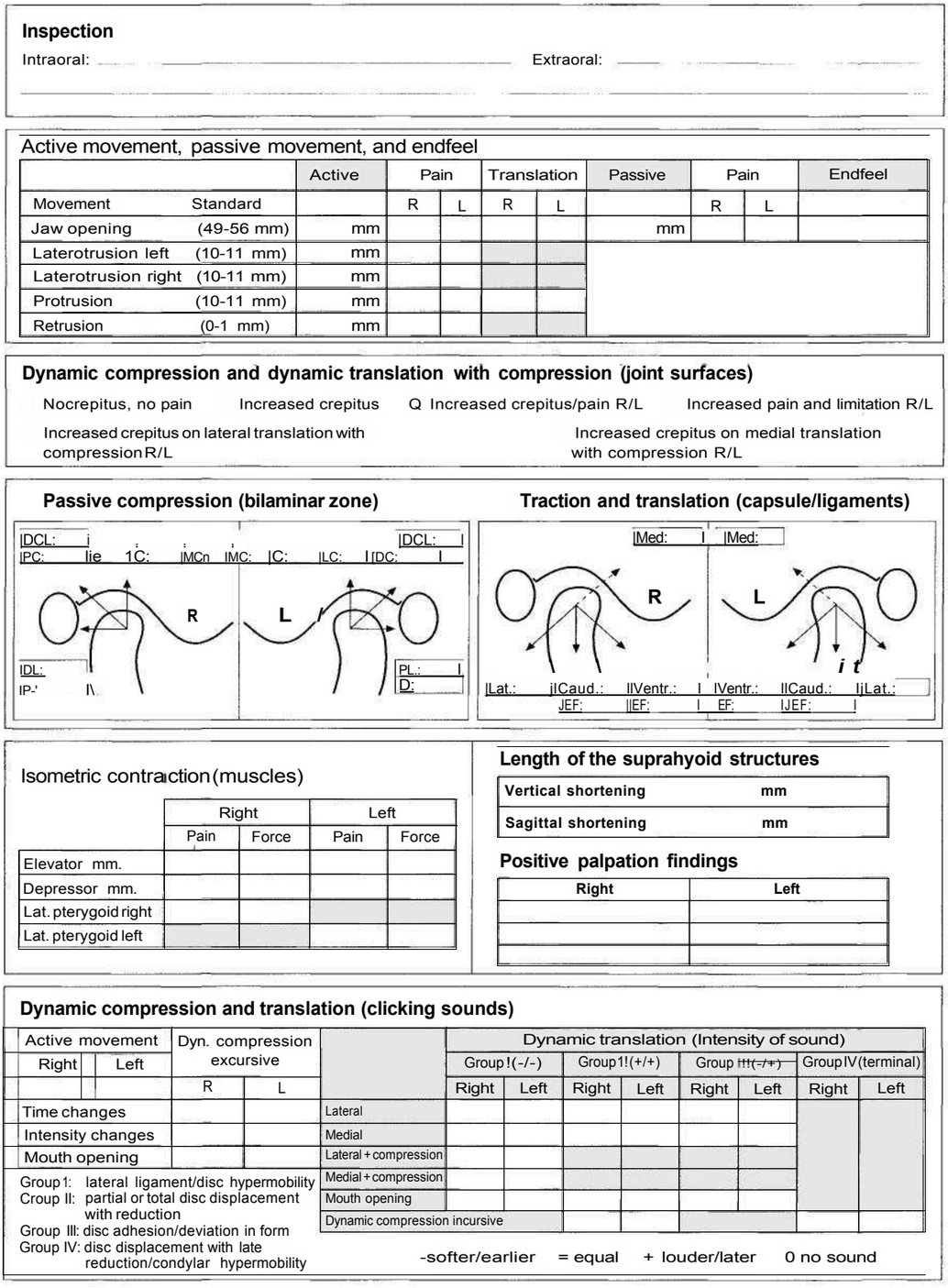
The *reverse side of the examination form* serves to document tissue damage. After a brief intraoral and extraoral inspection, the active movements are recorded here and in some cases these are complemented by passive movements. Next the individual structures of the masticatory system are systematically tested in the following sequence:

- First, dynamic compressions and dynamic translations with compression are applied to test the joint surfaces.
- This is followed by testing of the bilaminar zone by means of passive compressions.
- Translations and traction allow specific loading of the joint capsule and ligaments.
- Functional testing of the muscles of mastication is accomplished through isometric contractions rather than by palpation.
- Joint play techniques and isometric contractions are used to help distinguish between arthrogenic and myogenic problems.
- Finally, dynamic tests are used to differentiate clicking sounds in the joints,



Inspection

Intraoral: Extraoral:

Active movement, passive movement, and endfeel

		Active	Pain		Translation		Passive	Pain		Endfeel
Movement	Standard		R	L	R	L		R	L	
Jaw opening	(49-56 mm)	mm					mm			
Laterotrusion left	(10-11 mm)	mm								
Laterotrusion right	(10-11 mm)	mm								
Protrusion	(10-11 mm)	mm								
Retrusion	(0-1 mm)	mm								

Dynamic compression and dynamic translation with compression (joint surfaces)

Nocrepitus, no pain | Increased crepitus | Q Increased crepitus/pain R/L | Increased pain and limitation R/L

Increased crepitus on lateral translation with compression R/L

Increased crepitus on medial translation with compression R/L

Passive compression (bilaminar zone)

DCL: PC: ie 1C: MCn MC: C: LC: DC: DCL:

R L

DL: IP-' PL: D:

Traction and translation (capsule/ligaments)

Med: Med:

R L

Lat.: Caud.: Ventr.: Ventr.: Caud.: Lat.:

JEF: EF: EF: JEF:

Isometric contraction (muscles)

	Right		Left	
	Pain	Force	Pain	Force
Elevator mm.				
Depressor mm.				
Lat. pterygoid right				
Lat. pterygoid left				

Length of the suprahyoid structures

Vertical shortening	**mm**
Sagittal shortening	**mm**

Positive palpation findings

Right	Left

Dynamic compression and translation (clicking sounds)

Active movement		Dyn. compression excursive			Dynamic translation (Intensity of sound)							
					Group I (-/-)		Group II (+/+)		Group III (-/+)		Group IV (terminal)	
Right	Left	R	L		Right	Left	Right	Left	Right	Left	Right	Left
Time changes				Lateral								
Intensity changes				Medial								
Mouth opening				Lateral + compression								
				Medial + compression								
				Mouth opening								
				Dynamic compression incursive								

Group 1: lateral ligament/disc hypermobility
Croup II: partial or total disc displacement with reduction
Group III: disc adhesion/deviation in form
Group IV: disc displacement with late reduction/condylar hypermobility

-softer/earlier = equal + louder/later 0 no sound

138 Reverse side of form
This side has spaces for all the information necessary for the tissue-specific examination of the extraoral portions of the masticatory system. Entering the individual findings with a defined color-coding system allows a quick and convenient overview of which structures are adapted and which are not, as well as the corresponding loading vectors.

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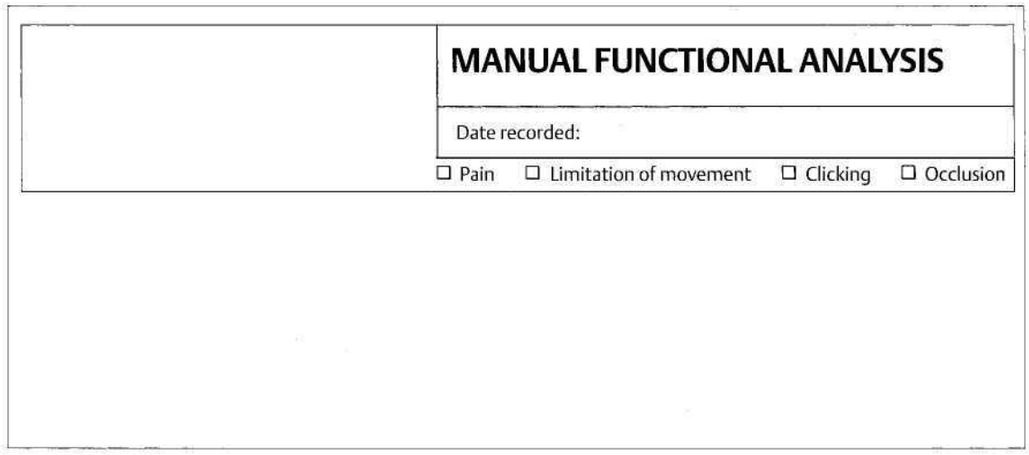
Patient History

The patient history is the foundation and a prerequisite for the diagnosis and treatment of functional disturbances, Together with the examination findings, it is used primarily in attempting to identify all regions of the masticatory system that have undergone structural damage (Okeson 1998). It serves further to help recognize the necessity for additional therapeutic measures and should protect both the patient and the clinician from failure (Nilges 1996). The history should be taken with the patient sitting upright in a quiet, relaxed atmosphere, ideally away from the treatment room.

As a rule, the general history can be adequately elicited by using a questionnaire. Eye contact and a friendly, interested demeanor on the part of the clinician promotes body language that will enhance nonverbal communication. If the patient's descriptions become too long-winded, the clinician should politely interrupt and guide the discussion back to the relevant main questions of the specific history and the most prominent current symptoms. By repeating and summarizing the patients comments, the interviewer can help avoid misunderstandings,

139 General patient data
To the left of the examination form heading is a box for the imprint data from the patient's insurance card. To the right, under the recording date, the patient is to check one or more of the main symptom groups.



The procedure followed for the *specific history* is based upon the assumption that the dentist is able to recognize symptoms in his/her area of specialty and reproduce them at will, In the introduction we identified two major divisions of the diagnostic phase:

- "What does the patient have?" or "Is a loading vector present?" and
- *"Why* does the patient have this loading vector?" or "Are corresponding occlusal influences present?".

Without evidence of a loading vector or, to put it another way, without the ability to repeatedly demonstrate a lesion that causes local or projected pain, there is no rationale for dental treatment, contrary to what was often previously assumed. Therefore all questions related to the "why?", that is, concerned with influences, should at first be strictly avoided in taking the specific history. Background inquiries into possible causes and previous therapeutic considerations (e.g. descriptions of the psychosocial environment, psychological questionnaires, detailed descriptions of previous treatments, etc.) are usually very time-consuming, Therefore a structured, symptom-related, tissue-specific examination is preferred. If the reported symptoms cannot be reproduced by this, then the patient must be referred for evaluation of systems in other fields such as orthopedics, neurology, psychology, or otolaryngology. If, on the other hand, the symptoms can be provoked, a search for possible causes and influences is conducted. A basic rule following from this is to concentrate ones efforts on those patients for whom dental procedures seem reasonable as a primary or supplemental treatment,

For this targeted, clinically appropriate interview process, three main questions have proven useful over the past few years:

"What are the Complaints that Brought You to Me?"
A meaningful entry in the specific history is an exact description by the patient of the presenting symptoms. Here the patient will usually report symptoms such as pain, restricted movement, clicking sounds in the joints, tinnitus, vertigo, burning tongue, lump in the throat, or a nonspecific sensation of pressure and tension. If the patient exhibits only *one* symptom, the course of the specific history will usually be relatively simple.

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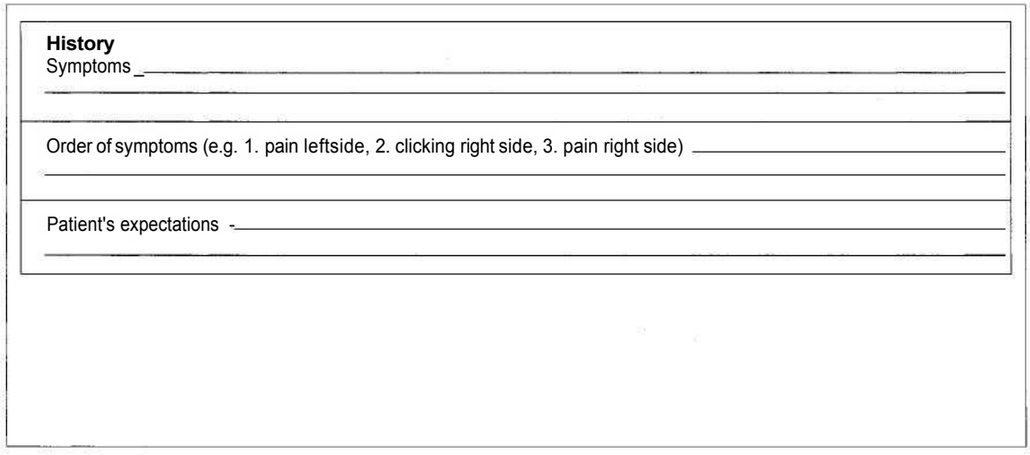
Whenever a *pain symptom* is reported, special attention must be given to its location, characteristics, initial occurrence, and the factors that increase its severity. The more vaguely a patient localizes the pain, the more specific the examiner's inquiry must be and the more strongly he must encourage the patient in his or her account. Pain that is described as localized and sharp, unlike dull, widespread pain, is quite unreliable for differentiating between arthrogenie and myogenic disturbances. Nevertheless, the *precise localization of pain,* and especially an account of whether a larger area of pain is provoked by one or more localized pains, is of great importance for the later progress of the examination.

If an area of pain extends from the angle of the jaw to the temporal region, the examiner must clarify:

- whether the problems all come from one point and spread out over the entire affected region
  or
- whether one part of the pain comes, for example, from a point in front of the ear and radiates into the temporal region while another part is caused by a "different" pain directly in the region of the angle of the jaw. In this case the clinician is dealing with two separate pains that just happen to be close together.



140 Special history
This section of the questionnaire is especially for patients with functional disturbances. It is essential that each patient answers the questions to his symptoms and his expectations. They can be supplemented as needed for individual cases.
The answers to these questions will determine the precise course of the examination as well as the type and extent of therapeutic measures to be introduced.

This distinction has definite consequences for the examination procedure that will follow as well as for the treatment, If one wishes to completely eliminate the patient's symptoms when the pains are separate, one must be able to elicit two pains that differ in their quality and location during the tissue-specific loading of the individual structures. If, for example, only one of the multiple pains reported in the patient history can be provoked, it will probably not be possible to rid the patient completely of all symptoms through dental treatment alone.

Therefore the fundamental rule is that if a symptom reported in the patient's history is to be eliminated through dental treatment then one must be able to repeatedly reproduce it during the course of the tissue-specific examination, An analogous practice is followed in the diagnosis of pulpitis: If the pain described by the patient cannot be reproducibly provoked and no lesion (such as caries) can be detected, one would not normally proceed with endodontic treatment.

After the patient has described his or her complaints more accurately the dentist summarizes the information once more and concludes by inquiring about other symptoms, For example: "If I understand you correctly, you have pain on the right side in front of the ear and at the angle of the jaw. Beyond that you have no other problems. There is no clicking in the joints, and you can always open your mouth as far as it is supposed to go. Is that correct?"

"Rank Your Problems in Order of Severity"
When multiple symptoms are reported the patient is asked to *rank* them according to their impact on his/her well-being (primary symptom, secondary symptoms),

"What Exactly Do You Expect from Me?"
At the end of the history taking there is the question of the expectations the patient had in coming to the dentist. One patient might seek only an explanation of a troublesome symptom but no further treatment, another may expect thorough diagnostic procedures and complete treatment, while a third may want only relief of the primary symptom.

The patient's expectations will have a substantial influence on the course of the examination and the treatment plan,

Taken together these three main questions of the specific history serve as a framework on which to organize the case presentation that will be given following the tissue-specific examination with manual functional analysis. This ensures that patients receive relevant information about the symptoms afflicting them and the answers to their questions,

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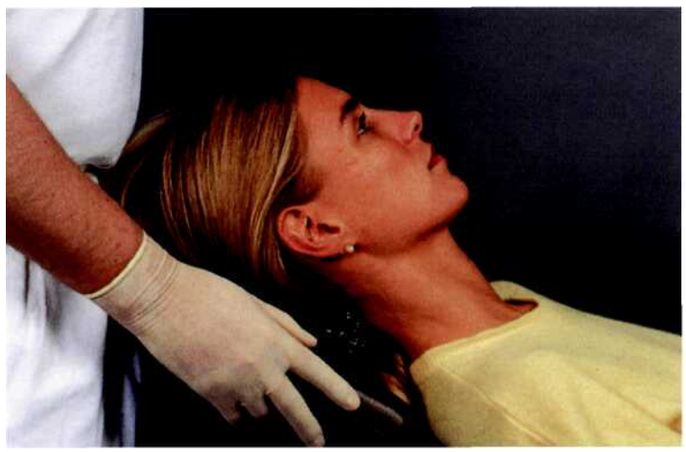
Positioning the Patient

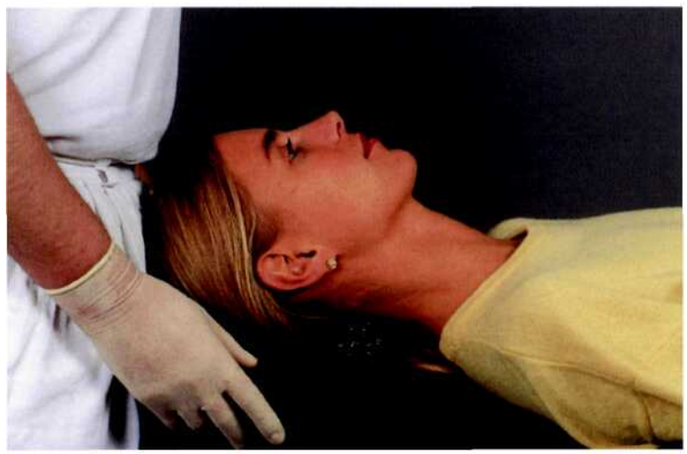
The position of the patient is an important condition for a specific examination and is different for each section of the examination:

- History taking is always carried out with the patient sitting upright.
- The examination procedures for manual functional analysis are performed from the 12 o'clock position, or more precisely, between the 11 and 1 o'clock positions. Three arrangements are possible, the choice depending upon the examiner, the patient, and the space available. These are:
  a) The patient is semi-reclined with the backrest at about a 45° angle and the examiner is standing upright behind the patient.
  b) The patient is supine and the examiner is standing upright.
  c) The patient is supine and the examiner is seated (the most effective variation).
- *Testing for harmful influences* can be carried out with the patient either fully reclined or sitting upright.

141 Examiner standing and patient semireclined
This arrangement is equally comfortable for both the clinician and the patient. It is normally chosen if for any reason the examiner prefers to work standing up or if the patient cannot recline fully because of a general orthopedic problem.



142 Examiner standing and patient fully reclined
This horizontal positioning of the patient with the examiner standing is appropriate only if the clinician is of short stature. Otherwise it would be difficult to stabilize the patient's head. Furthermore, a dental chair cannot normally be raised high enough for a taller clinician to examine the patient while maintaining an ergonomically sound posture.



143 Examiner sitting and patient fully reclined
The most frequently used arrangement for a tissue-specific examination is with the patient reclined and the clinician sitting. The examiner first adjusts the height of his/her stool so that the thighs are parallel with the floor or are at an angle of approximately 95° from vertical. Finally the height of the dental chair is adjusted. During palpation of the temporomandibular joints the elbows should be bent at a 90° angle.

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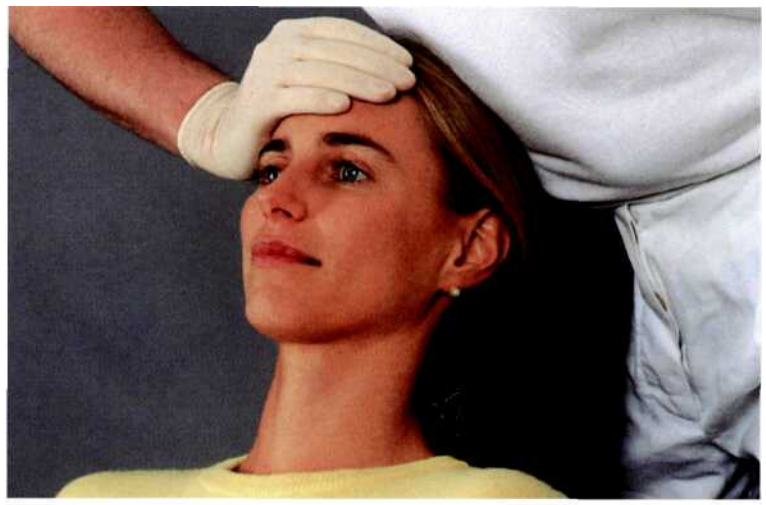
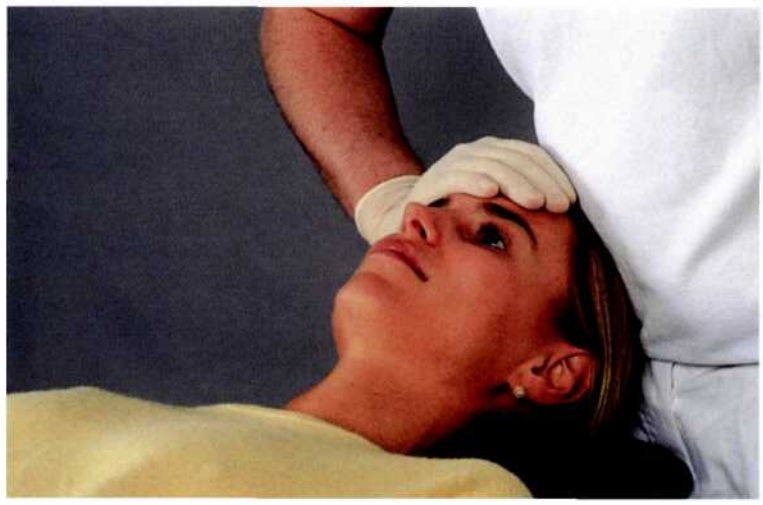
Manual Fixation of the Head

In addition to the correct positioning of the patient, optimal stabilization of the patient's head is an important condition for achieving reproducible results during the examination. Regardless of the patient's position, it is essential that the head of the patient be supported in all spatial dimensions at all times. A good examination technique requires that forces applied to the mandible in different directions cause no noticeable movements of the head. Not only does optimal stabilization have a positive effect on the patient's opinion of the examination procedure but it also has solid medical grounds:

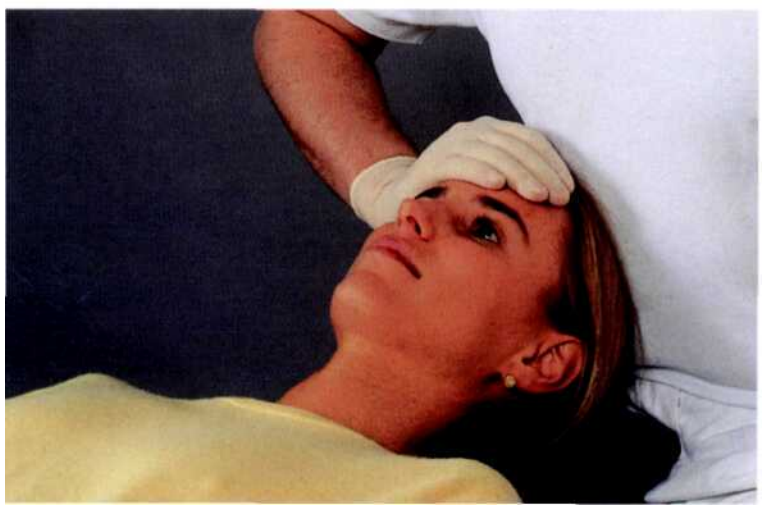
- Aggravation of a preexisting problem within the cervical spine must be absolutely avoided.
- Protection of the cervical spine of a patient with diffuse headache or tinnitus is of diagnostic importance. Placing stress on the cervical spine can in some cases precipitate tinnitus. The examiner, however, because he/she is performing a "temporomandibular joint examination" might mistakenly assume that the cause is arthrogenic.



144 Clinician standing and patient semireclined
This combination allows the dynamic tests and the isometric contractions to be carried out quite reliably. However, optimal stabilization of the patient's head is not always assured for the entire joint-play technique, and the clinician's back is bent during a large part of the examination. For follow-up exams in which only a few manipulations are to be carried out, however, this position is ideal.



145 Clinician standing and patient fully reclined
Short clinicians who like to stand while working at the dental unit can achieve satisfactory stabilization for almost all examination techniques with this arrangement. If the examination is to take place on a treatment table with adjustable height, the headboard must be shortened to achieve adequate fixation of the head for the various techniques.



146 Clinician sitting and patient fully reclined
The ideal combination for reproducible examination results is a fully reclined patient and a seated examiner. All dynamic tests and isometric contractions can be performed from the 12 o'clock position. All joint-play tests are performed for the right joint from the 1 o'clock position and for the left joint from the 11 o'clock position. During almost all tests the patient's head is stabilized in all three planes by the headrest, one of the clinician's hands, and the clinician's abdomen.

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Active Movements and Passive Jaw Opening with Evaluation of the Endfeel

Examination of the extraoral portions of the masticatory system begins with observation of active jaw movements. Active movements do not contribute to the differential diagnosis (Szentpetery 1993), but serve only to document the initial conditions and to verify the symptoms described by the patient. Note is made of the extent of movements in millimeters and any accompanying pain and its location (right/left). None of this in any way supports a differential diagnosis but it does serve to test the conclusiveness of the reported symptoms.

Attention is given to any alteration in the path of movement of the incisal point (deviations and deflections) as has been recommended earlier (Wood 1979), but these are not documented. Because deflection to one side, for example, can have different arthrogenic causes (ipsilateral hypomobility or contralateral hypermobility), it makes more sense to determine the *amount of condylar translation.* This is done by palpating the lateral poles of the condyles during opening and protruding movements. Under normal conditions a condyle translates almost to the crest of the eminentia.

147 Chart for recording findings from active movements, passive jaw opening, and endfeel

Active movement, passive movement, and endfeel

		Active	Pain		Translation		Passive	Pain		Endfeel
Movement	Standard		R	L	R	L		R	L	
Jaw opening	(49-56 mm)	mm					mm			
Laterotrusion left	(10-11 mm)	mm								
Laterotrusion right	(10-11 mm)	mm								
Protrusion	(10-11 mm)	mm								
Retrusion	(0-1 mm)	mm								

Jaw opening is usually measured between the incisal edges of the incisors (Hesse 1996) and to this is added the overbite (anterior vertical overlap). This is especially meaningful in patients with a "deep bite" (large vertical overlap). The amount of "normal" jaw opening averages 53-58 mm (Ingervall 1970, Agerberg 1974, Wood 1979). Even 6-year-olds have jaw openings of 43-45 mm (Landtwing 1978, Vanderas 1992). Although women in general have more mobile joints (Beighton et al. 1973, Carter and Wilkinson 1964, Hesse 1996), men are able to open their jaws wider by 3-5 mm. According to Agerberg (1974a-d), jaw opening is directly related to body size. It decreases significantly with age and measures only 45-53 mm in 70-year-olds (Agerberg and Osterberg 1974, Lysell 1984, Mezitis et al. 1989).

In a selected group of patients with temporomandibular joint problems average jaw openings were 45 mm in men and 39 mm in women (Carlsson and Swardstrom 1971). Contrary to the general clinical impression, a correlation between the extent of active mandibular movement and overall joint mobility is either nonexistent (Westling and Helkimo 1992) or is present only weakly in isolated cases (Dijkstra et al. 1994, Hesse 1996).

While there is little disagreement on the definition of a physiological jaw opening, views vary on what constitutes a *limitation of jaw opening:* Because only 1.2% of all (not selected) adults have a jaw opening of less than 40 mm (Bitlar et al. 1991), Okeson (1998) accepts this measurement as the boundary, whereas Ingervall (1970) considers a value of 41-42 as a reasonable boundary for limitation of opening. Clinically, however, the many deliberations over establishment of a cut-off value are of no relevance, because a patient may have a measurement of 48 mm, for example, and still be significantly limited because the value was 62 mm before some past event. Regardless of the "scientific boundary" (40-42 mm) a limitation of jaw opening always exists when a patient's mandibular mobility is objectively found to be less than it was at a previous examination.

There are significantly fewer statements in the literature on the physiological extent of *lateral movements.* Ingerval (1970) gives average values of 9.8-10.5 mm, Agerberg and Osterberg (1974) report 8.7-8.8 mm, and Hesse (1996) reports 10.0-10.5 mm. There is no significant difference between males and females. The ratio of jaw opening distance to lateral movement in a healthy system is approximately 6 :1 (Dijkstra et al. 1998). Lateral movements of less than 8 mm are generally classified as restricted (Ingervall 1970, Okeson 1998).

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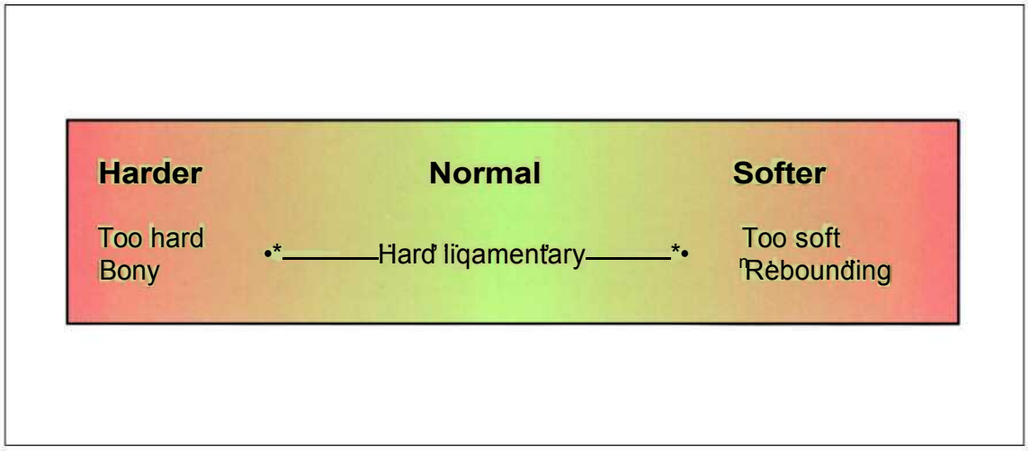
Protrusive movements are neglected in the literature and in the clinics even more than lateral movements. Still, the extent of protrusion (i.e. condylar translation) provides important information on the mobility of the joints, and therefore reveals over how broad a surface the forces are distributed (stress = force per unit of area). The reports range from 8.8 mm (Bergholz 1985) and 9.1 mm (Hesse 1996). Likewise, there is no sex-related difference in the extent of protrusion. Children give somewhat higher protrusive measurements than adults until the age of 10 years when their measurements are basically the same as those made on adults (Ingervall 1970).

Protrusive movements of less than 7 mm are considered to be restricted, although they are not always signs of pathology that urgently calls for treatment. It is especially important to test patients for restriction of lateral and protrusive movements following temporomandibular joint surgery and orthodontic or orthognathic surgery.

The determination of active movements is followed by an investigation of passive movements. This is to be done only on patients with limited but painless jaw opening, because painful joints will not permit the procedures needed for differential diagnosis of a limitation.



148 Endfeel during passive jaw opening

At the end of an active movement every healthy joint can be moved farther through a certain amount of space. This can occur only through the application of external force and is therefore referred to as passive *movement* (Kimberly 1979). In the early days of manual functional analysis all the mandibular movements were followed by tests of further passive movement. However, as 10 years of clinical experience has shown, this provided no additional diagnostic or therapeutic information so that passive tests are now applied only to the jaw-opening movement.

The extent of passive jaw opening, also referred to by some authors (Hesse et al. 1990) as the "endfeel distance," has been reported in one study (Westling and Helkimo 1992) as 1.2 mm and in another (Agerberg and Osterberg 1974) as 2.1 mm. Still more specific measurements can be found in the work of Hesse (1996), who reports an endfeel distance in men of 3.0 ± 1.1 mm under a force of 44.6 ± 7.2 N and in women, 3.8 ± 1.4 mm under 37.1 ± 2.1 N. The extent of mandibular movement is influenced by the ligaments, capsule, intra-articular structures, muscles, fascia, and the skin (Evjenth and Hamberg 1985, Hesse 1996).

Limitation of jaw opening is always accompanied by shortening one of more of the above-mentioned structures (Schneider et al. 1988). Therefore, at the end of passive jaw opening the so-called endfeel is recorded (Fig. 156ff).

The *endfeel* is the feeling that the examiner detects at the end of a passive movement. It is always determined by the structures that are limiting the movement (Groot Landeweer and Bumann 1991). In healthy joints the endfeel is "hard ligamentary" and is not accompanied by pain (Cyriax 1979, Kaltenborn 1974, Janda 1974, Lewitt 1977, McCarroll et al. 1987, Hesse et al. 1990, Groot Landeweer and Bumann 1991, Bumann et al. 1993, Bumann and Groot Landeweer 1996b, Hesse 1996).

There are various classifications of the endfeel in the temporomandibular joint (Cyriax 1979, Evjenth and Hamberg 1985, Groot Landeweer and Bumann 1991, Hesse 1996). Clinically a distinction is made between physiological and structurally pathological endfeels (Figs. 148 and 161). Although there has been little inter-examiner agreement on the concept of the endfeel (Lobbezzoo-Scholte et al. 1994), Hesse (1996) could demonstrate a distinct correlation between the endfeel and the so-called "craniomandibular stiffness." The evaluation of a combination of the extent of passive movement and the clinical endfeel is therefore a reliable parameter for the differential diagnosis of limitations of movement. Neither the endfeel nor the extent of passive movement helps to differentiate between myogenic and arthrogenic problems, as, for example, claimed by Fuhr and Reiber(1989).

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149 Active jaw opening
A mark has been made on the lower incisors at the level of the incisal edge of an upper incisor in maximal occlusion. Active jaw opening can be measured directly or by measuring the incisal edge distance as shown here and adding to it the anterior vertical overlap ("overbite").

Right In the record of findings, green ink is used to enter the amount of pain-free movement and red is used for painful movements.

Active
51

150 Active movement of the mandible to the left
To measure lateral mandibular movements, the upper midline is first projected onto the labial surface of a lower incisor. Then the patient executes a maximal lateral movement and the distance between the upper midline and the mark on the lower tooth is measured.

Right: The measurement is entered in the chart in the same way as the jaw-opening distance. The "normal" range is 10.5 ±2.7 mm.

Active
51
12

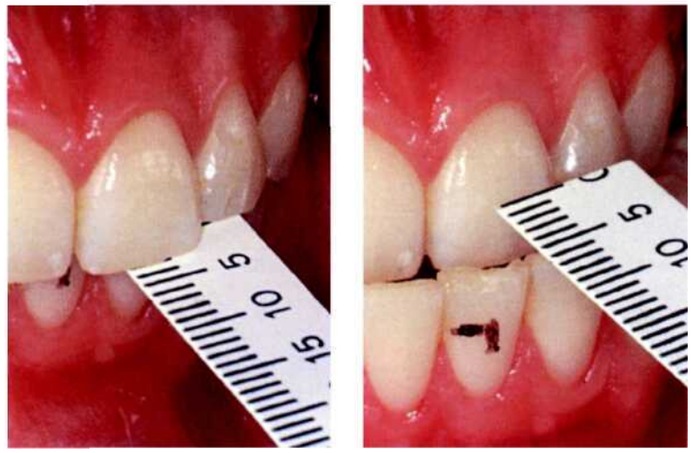
151 Active movement of the mandible to the right
After a maximal movement of the mandible to the right, the distance from the upper midline to the lower mark is measured.

Right: Again, the specific entry is made on the form as was done for the jaw-opening value. The norm for men is 10.2 + 2.3 mm and for women 10.3 ± 3.4 mm. The normal values given here for the two sides are taken from studies by Hesse (1996).

Active
51
12
11

152 Active protrusive movement
To determine the extent of protrusion, the horizontal overlap ("overjet") is measured first and then added to the distance between the upper labial surface and the lower incisal edge after maximal protrusion. This can be done with either a simple ruler or with the back side of a commercial sliding caliper.

Right: Entry in the patient's record is made in green or red. Normal values are 9.0 + 2.8 mm for men and 9.1 ± 1.8 mm for women.



Active
51
12
11
9

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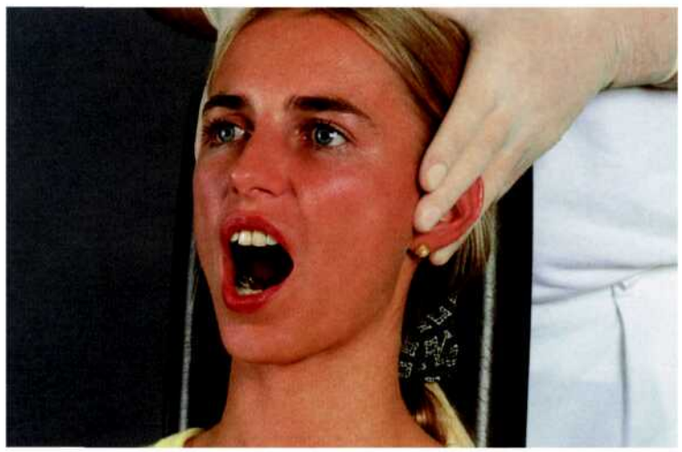
Active
51
12
11
9
1

153 Active retrusive movement
First the horizontal overjet is measured in habitual occlusion with a ruler or sliding caliper. Then the patient is instructed to "pull the lower jaw back" or "push the upper jaw forward" as far as possible. The amount of retrusion can then be read directly, although this is of no importance in making a differential diagnosis.

Left: The chart entry is made in the usual manner. Values range from 0 to 2 mm.

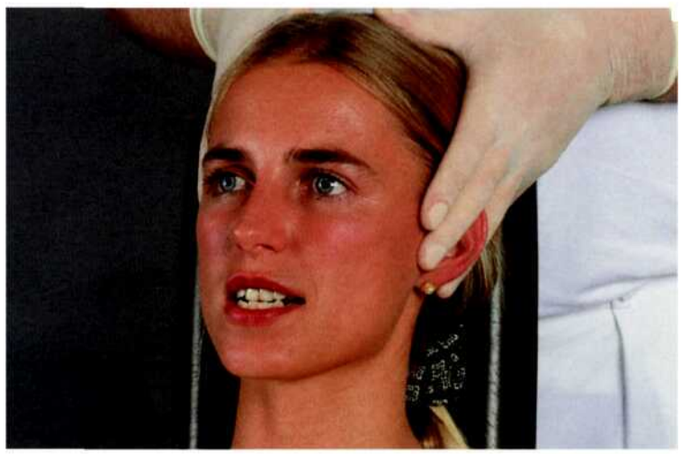
Translation	
R	L
✓	+



154 Translation of the condyles during active jaw opening
A qualitative evaluation of condylar translation can be made by palpation. Normally during jaw opening the condyles move only to the crest of the articular eminence. The examiner can determine normal mobility (/), hypomobility (-), or hypermobility (+).

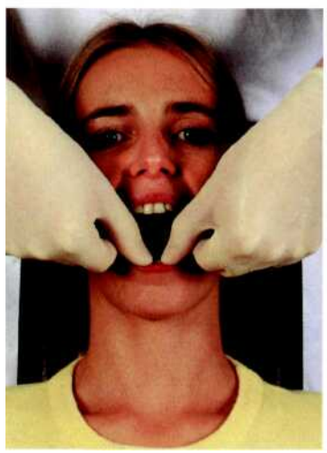
Left: Example of chart notations using the corresponding symbols. Upon jaw opening, mobility of the right condyle was normal while there was hypermobility of the left condyle.

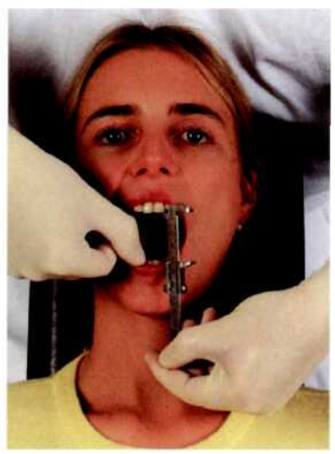
Translation	
R	L
–	✓



155 Translation of the condyles during active protrusion
The extent of condylar translation during protrusive movement is also determined. A movement that stops just short of the crest of the eminence is considered normal, but a condyle that passes beyond the eminence is considered hypermobile. If the condyle moves out of the fossa only slightly or not at all, it is hypomobile.
Left This entry in the examination form indicates that the right condyle was hypomobile and the left had normal mobility. This test replaces the documentation of deviation and deflection.

Passive
51+4





156 Further passive jaw opening beyond active opening
Passive jaw opening is usually executed with both hands. The index or middle fingers are placed on the upper premolars and the thumbs on the lower incisal edges. The patient opens the mouth as far as possible and at the end of the active movement the clinician assists further opening. The amount of passive movement is evaluated. If the one-handed technique is used the distance can be measured with the other hand.

Left: Chart entry.

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157 Section of examination form dealing with passive jaw opening

If there is pain upon passive jaw opening, the amount of movement is written in red. Then the amount offeree needed to elicit pain is indicated by means of red plus signs (+, ++, +++) written in the box for the painful side. The endfeel is recorded only when jaw opening is painless, otherwise the patient will reflexively tense the muscles.

Passive	Pain		Endfeel
	R	L	

158 Limited jaw opening resulting from skin changes in scleroderma

Left: In a patient with scleroderma, taut cords form in the skin during passive jaw opening and the endfeel is "too hard."

Right: Sclerosing of the skin causes typical limitation of jaw opening to 30-35 mm. This must not be confused with a nonreducing disk displacement.

159 A "too soft endfeel" with passive jaw opening

Left: An endfeel that is "too soft" accompanied by condylar hypermobility. The length of the jaw-closing muscles limits opening movements when there is lengthening or overstretching of the capsule and ligaments.

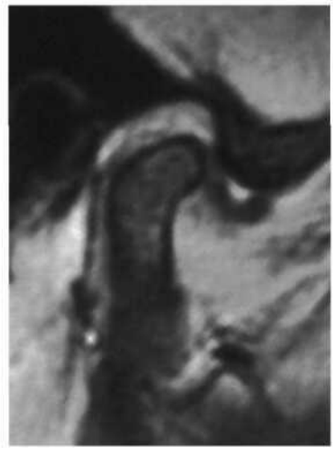
Right A "too soft" endfeel accompanied by reduction of jaw opening. Tensed or shortened elevator muscles are limiting the extent of jaw opening.

160 An endfeel that is "too hard" and "rebounding"

Left: A "too hard" endfeel with restricted jaw opening. The shortened capsule and ligaments are limiting jaw opening.

Center. MRI image of the nonreducing disk displacement at maximal jaw opening.

Right: Rebounding endfeel at the end of a restricted jaw-opening movement. The nonreducing anterior disk displacement limits jaw opening.



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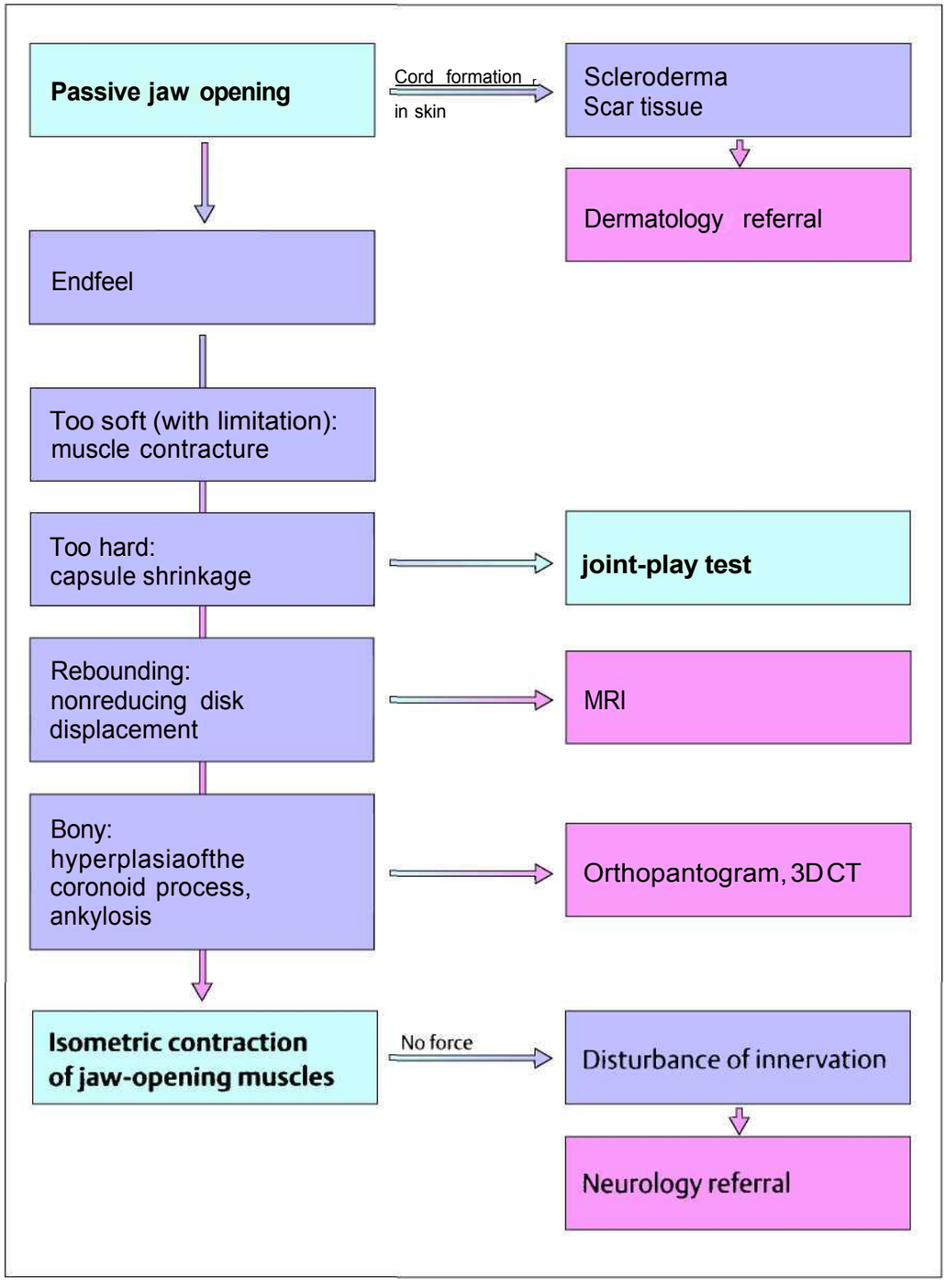
Differential Diagnosis of Restricted Movement

Nonpainful limitations of movement can be differentiated only by evaluating the endfeel after passive movement. The ability to make an exact determination of the endfeel requires practice and a little experience. This is the only method by which structural causes of restricted movement can be discovered. The elicited endfeel is merely verified secondarily through other methods such as the joint play technique, radiographs, or MRI. These, however, are not indicated for use as primary differential diagnostic procedures. During the passive jaw-opening procedure 92.5% of patients report a drawing sensation in the preauricular region (Hesse 1996). This false perception can be accounted for by the stretching of the joint capsule and the lateral ligament.

If passive jaw opening causes the patient pain, the endfeel cannot be used to aid in making a differential diagnosis of limited movement. Therefore, when the signs and symptoms include the combination "pain and restricted movement," the pain must be treated first before an adequate differential diagnosis of the restricted movement can be made.



161 Examination sequence when there is a nonpainful limitation of jaw opening

The diagram shows the sequence in which the examination techniques are to be carried out. In a patient with scleroderma tight cords appear in the skin during passive jaw opening (Fig. 158). In these cases the dentist can prescribe mobilization exercises ("jawsercises," Korn 1994) and refer the patient to a dermatologist if the disease is not already being treated.

In patients with restricted jaw opening the endfeel may assume one of four characteristics: too soft, too hard, rebounding, or bony.

- Reduced jaw opening produced by shortening of the muscles gives a "too soft" endfeel during passive jaw opening (Croot Landeweer and Bumann 1991, Stengengeeta!1993).
- A "too hard" endfeel indicates a shortened capsule (Bumann et al. 1993). This finding can be corroborated by testing the endfeels from anterior translation and inferior traction (Fig. 201 ff).
- A "rebounding" endfeel is evidence of a *nonreducing disk displacement* (Fig. 160). This can be verified through MRI. However, a nonreducing disk displacement seen on a MRI is not necessarily the cause of restricted movement. Therefore the MRI cannot be relied upon as the primary diagnostic tool.
- A "bony" endfeel indicates osseous changes. Disrupted innervation can be ruled out through isometric contraction of the jaw-opening muscles.

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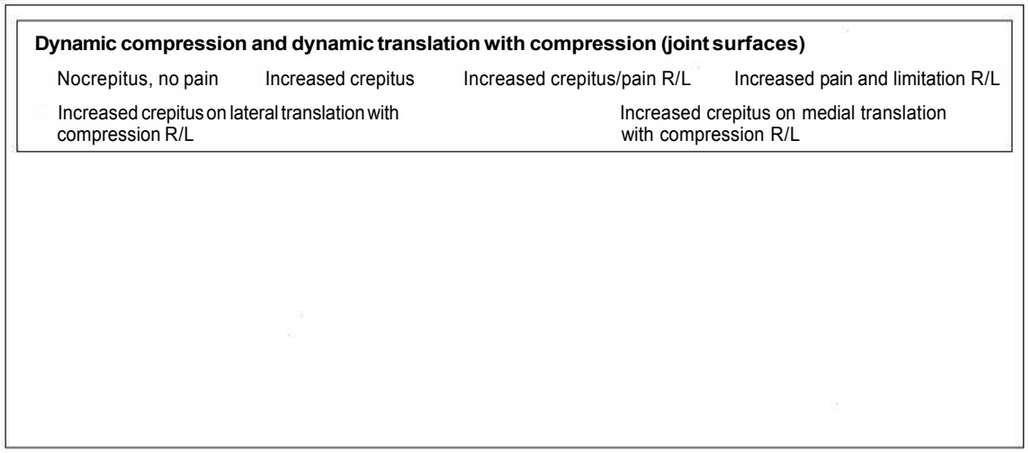
Examination of the Joint Surfaces

The functional articulating surfaces of the temporomandibular joint are the fibrocartilaginous articular portions of the temporal bone and the condylar process of the mandible as well as the articular disk. Because the resultant force of the muscles of mastication is directed anterosuperiorly (Chen and Xu 1994), this is where the functional joint surfaces are found.

The proteoglycans in the fibrous cartilage are responsible for the disk's resistance to compression (Kopp 1978, Axelsson et al. 1992). Although a reduced content of proteoglycan significantly alters the compressive characteristics of cartilage, it has no negative effect on its frictional properties (Pickard et al. 1998). The ability of the joint surfaces to deform serves to cushion and distribute peaks of stress. It also helps lubricate the contacting joint surfaces to minimize friction and wear (Mow et al. 1993, Murakami et al. 1998). The conformity of the joint surfaces plays a decisive role in the lubrication process (Nickel and McLachlan 1994b). The coefficient of friction of a healthy joint is 0.007. Lavage can cause this to increase three-fold, and following introduction of hyaluronic acid friction is reduced again by half (Mabuchi et al. 1994).

162 Form for recording signs and symptoms
Excerpt from the manual functional analysis examination form for recording the results of the dynamic compression and dynamic translation tests for the current degree of adaptation of the joint surfaces. The upper row is for the results of the dynamic compression test and the lower row is for the dynamic translation test. With these findings one can differentiate between osteoarthrosis, osteoarthritis, and capsulitis of the bilaminar zone with nonreducing disk displacement.



The joint surfaces in the temporomandibular joint become deformed when loaded (Moffet 1984). Destructive *changes in the joint surfaces* occur six to eight times more frequently in women than in men (Toller 1973, Rasmussen 1981, Tegelberg and Kopp 1987), which indicates that either the adaptability of women's joints is less or the harmful influences are stronger. The effect of a force depends on its amplitude, frequency, and duration (Gradishar and Porterfield 1989, Bell 1990).

Motion reduces the deforming effects. Conversely, restrictions of movement intensify the deforming effects. As long as the adaptability of the tissue is not exceeded, the articulating surfaces of the temporal bone and condyle can become remodeled (adapted), but otherwise degenerative changes will occur in the joint surfaces (Moffet et al. 1964, Solberg 1986, Copray et al. 1988). The capacity for progressive and regressive adaptation of the osseous portions of the joints is present throughout life (Griffen et al. 1975). Surgical osteotomies on one or both jaws are followed by distinct adaptive changes of the condyle in approximately 23% of adult patients (Hoppenreijs et al 1998). Adaptive changes of the condyle and fossa could also be found in more than half the joints after mandibular midline osteodistraction treatment to stimulate osteogenesis (Harper et al. 1997). The disk, on the other hand, is not capable of cellular remodeling (Moffet 1984). Therefore, loading of the disk can produce only reversible (elastic) or irreversible (plastic) deformation. Histologically, slightly elevated levels of functional loading lead to thickening of the cartilage on the joint surfaces (Muir 1977, Radin et al. 1978). A further increase in loading interferes with fluid exchange and disrupts the supply of nutrients (Gradishar and Porterfield 1989, Haskin et al. 1995), thereby causing increased tissue degeneration (Ateshian and Wang 1995). Short term loading (less than 2 minutes) of the articular cartilage lowers the coefficient of friction, whereas a load applied for 45 minutes causes a five-fold increase in friction! Cyclic short-term loads allow a high water content in the cartilage and are accompanied by reduced friction (Nickel and McLachlan 1994a). Neither occlusal attrition nor the thickness of the cortical layer of bone as seen in a radiograph provides any reliable indication of the current thickness of the fibrocartilaginous joint surfaces (Pullinger et al. 1990). Contours of the bone seen on the radiograph do not correspond to the actual contours of the joint surfaces!

A noninvasive determination of the stages of regressive adaptation of the joint surfaces can only be made clinically, not by imaging procedures. For this we use the so-called dynamic compression and dynamic medial and lateral translation (sometimes with compression). The fundamentals and clinical procedures are described on the following pages.

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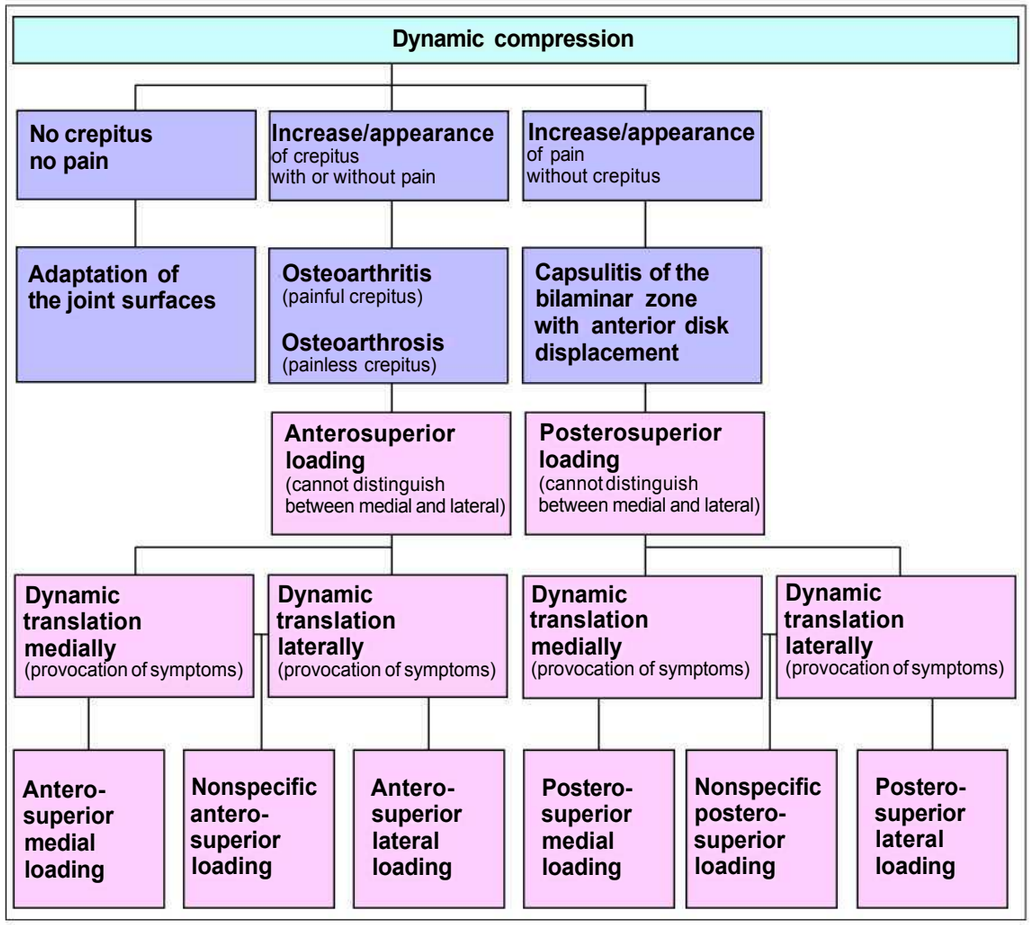

163 Examination techniques and their usefulness in differentiating between injuries/lesions of the joint surfaces
Active movements, dynamic compressions, and medial and lateral dynamic translations are all used to serve as nonmanipulated references for specific testing of the joint surfaces. Through the findings from the dynamic compression test it is possible to conclude whether there is an adapted joint surface, osteoarthrosis, osteoarthritis, or capsulitis of the bilaminar zone in the presence of a nonreducing disk displacement (pp. 70-74).
Use of the dynamic translation test permits further determination of whether a regressive adaptation and its associated loading vector lie more medially or laterally. This knowledge is essential later during clinical testing of influences to determine whether or not there is a causal relation with occlusal disturbances.

Frequently temporomandibular joints with obvious radiographic changes in the bone show only insignificant clinical symptoms or none at all (Mejersjö and Hollender 1984). Because of this the purpose of a specific functional joint-surface test is only to determine whether or not the joint surfaces are adapted or not. Diagnostically and therapeutically, it is of minor importance how the structures are represented by imaging procedures.
There is a close correlation between regressive adaptations of the functional joint surfaces and *crepitus* (Boering 1994, Hansson and Nilner 1975, Bates 1993, Pereira et al. 1994). Controlled studies indicate that crepitus is a reliable clinical sign of osteoarthrits (Holmlund and Axelsson 1996). Within a selected group of temporomandibular joint patients, 3-24% were found to exhibit rubbing sounds (Bates et al. 1994, Zarb and Carlsson 1994).

Sometimes the degeneratively altered joint surfaces are also painful. Even though in the 20th embryonic week the disk is supplied with numerous nerve endings, no innervating structures remain to be seen after birth (Ramieri et al. 1996). Therefore the disk can be excluded as a source of pain. As long as the temporal and condylar joint surfaces are still covered with cartilage, they too are unable to give rise to pain. It is only when subchondral bone is exposed that the nociceptors transmit corresponding pain sensations (Quinn 1989, Kamminishi and Davis 1989).

Conventional clinical examination methods can diagnose initial osteoarthrotic changes only with a low degree of specificity and sensitivity. Therefore manual functional analysis employs not only active protruding and opening movements, but also *dynamic compressions and translations*, which load the corresponding joint surfaces more heavily during movements. In this way even compensated joint surface changes can be discovered early by provoking a painful response.
Crepitus is a primary examination parameter. The examiner must determine whether at any given moment during manipulation the rubbing sound occurs more loudly and distinctly than during nonmanipulated active movements (protrusion and opening). In addition it should be determined if there is any pain produced by compression. Whenever there are painful alterations in the joint surfaces, the endfeel of inferior traction and anterior translation must be tested before any conclusions are formed about the effectiveness of a possible unloading of the joint. The results of the tests of the joint surfaces allow the following deductions to be made:

- *Adaptation:* no crepitus and/or no pain during acfive movements and dynamic tests
- *Compensation:* crepitus and/or pain only during the dynamic tests
- *Decompensation:* crepitus and/or pain during active movements and during dynamic tests.

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Manifestations of Joint Surface Changes

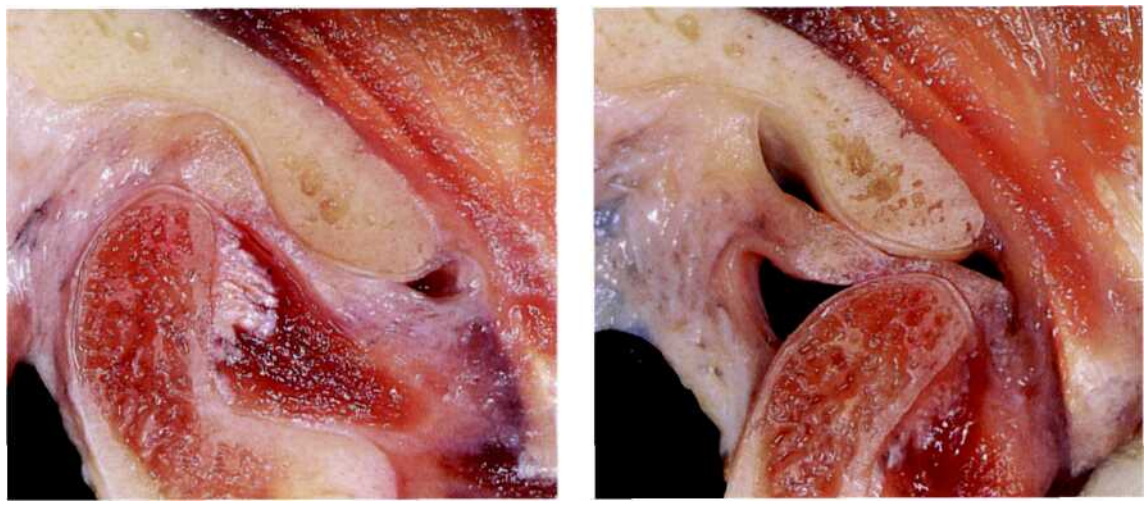
Unlike other synovial joints the temporomandibular joint has joint surfaces of fibrous cartilage, a highly differentiated connective tissue with no blood vessels or nerve endings. Compared with hyaline cartilage, fibrous cartilage is less easily deformed because of its higher fiber content (Gay and Miller 1978). The mucopolysaccharide content of the synovial fluid is responsible for lubrication of the joint surfaces (Smith 1982). This is why there are normally no noises or pain during active movements and during dynamically influenced movements.

- An increase of crepitus during dynamic compression in the absence of pain indicates *osteoarthrosis,* a regressively adapted, noninflammatory stage of joint surface damage.
- If crepitus and pain are both provoked there is *osteoarthritis,* an inflammatory stage of joint surface damage.

The examiner must make certain that the provoked pain is intensified by application of compression and not by a nonspecific joint loading due to increasing jaw opening.

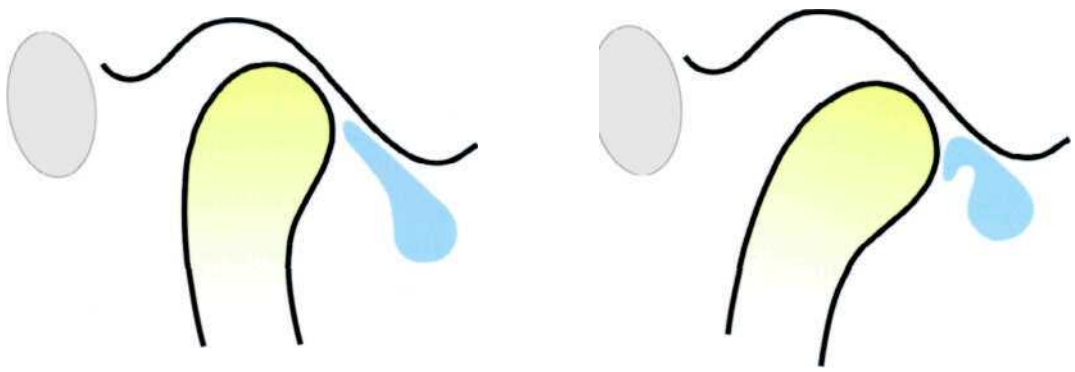
164 A healthy joint
Left: Anatomical preparation of a right temporomandibular joint with the jaws closed. The rounded condyle is covered by a uniform layer of fibrous cartilage. There is no fibrous cartilage on the superior and posterior portions of the fossa. Only the posterior slope and the crest of the articular eminence exhibit functional joint surfaces.

Right: During jaw opening there are no grating sounds or pain.



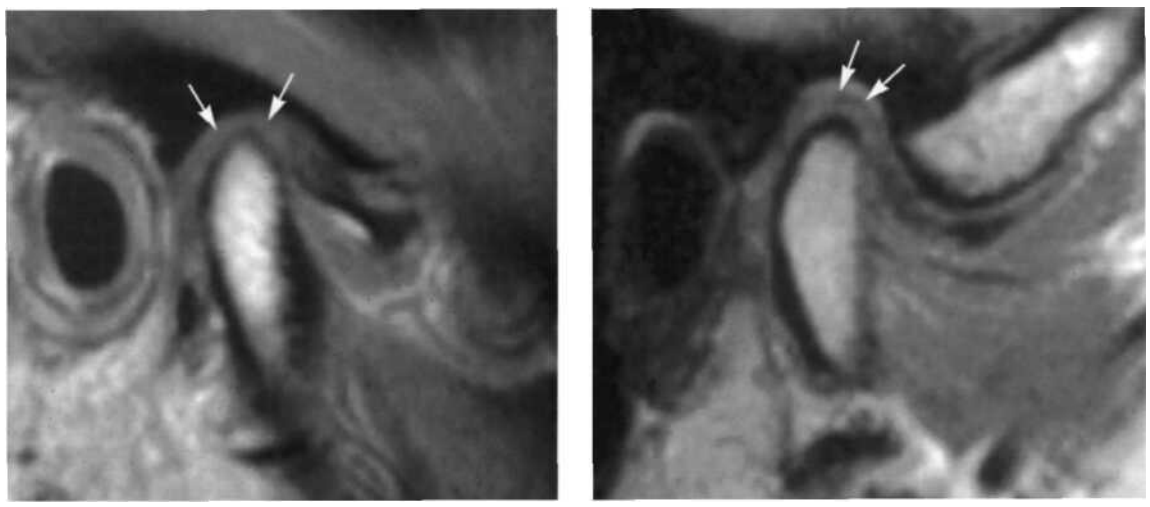
165 Nonreducing anterior disk displacement
If the disk is displaced anteriorly when the mouth is closed, the top of the condyle will be covered by part of the overstretched bilaminar zone, which at this time acts as the articulating surface. The compression test will intensify pain in this area.

Right: As the jaws are opened, the condyle pushes the disk ahead of itself, thus increasing pain and limitation of movement.



166 Adaptation of the bilaminar zone after anterior disk displacement
Left: Dynamic compressions are associated with pain and limitation of movement only if the bilaminar zone has not adapted as seen in this MRI (light gray, arrows).

Right: This MRI shows an adapted (fibrosed) bilaminar zone as dark gray (arrows). Under the right circumstances dynamic compression will provoke no pain and the joint will require no treatment.



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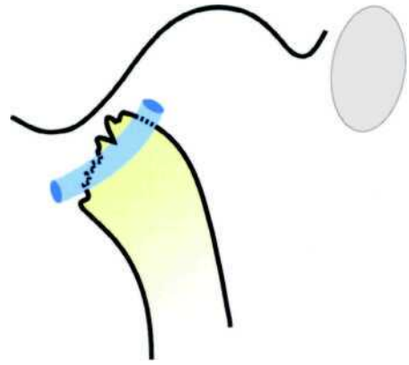
In contrast with other definitions (Stegenga 1991), osteoarthritis is not a joint surface lesion with inflammation of the surrounding soft tissues, but rather a destruction of fibrous cartilage with painful exposed subchondral bone.

Osteoarthrosis and osteoarthritis can occur with or without disk displacement and, as previously stated, may accompany disk perforation. It cannot be differentiated clinically for each individual case, but this is not relevant to the treatment.

Nonreducing disk displacement represents a special case. If under dynamic compression there is no crepitus but pain and limitation of the jaw-opening movement, *capsulitis of the bilaminar zone* with nonreducing disk displacement should be suspected. In this situation the disk is anteriorly displaced and no repositioning occurs during jaw opening. A portion of the overstretched bilaminar zone lies over the top of the condyle. If this portion has not become adapted through fibrosis, it produces pain that is increased by *dynamic compression.* Protrusion or jaw opening will further increase the pain so that the clinical appearance of restricted jaw opening results. The clinical presumptive diagnosis can be reinforced through passive superior compressions and, if necessary, verified by imaging procedures.

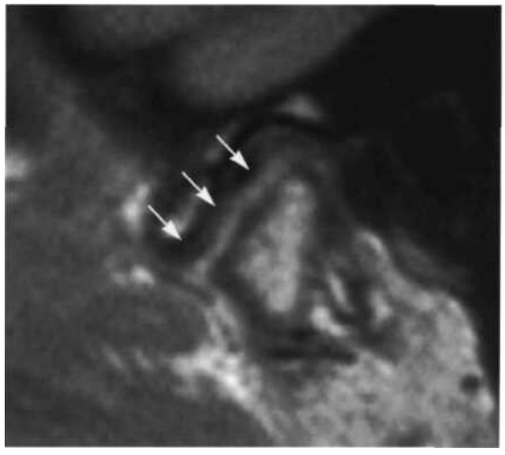
167 Perforation of the articular disk
Left: For diagnostic and therapeutic purposes, a disk perforation is regarded as a change in the temporal or the condylar joint surfaces. This type of joint surface damage usually has an anterosuperior loading vector. Treatment is always directed in the direction opposite the loading vector regardless of morphological relationships.

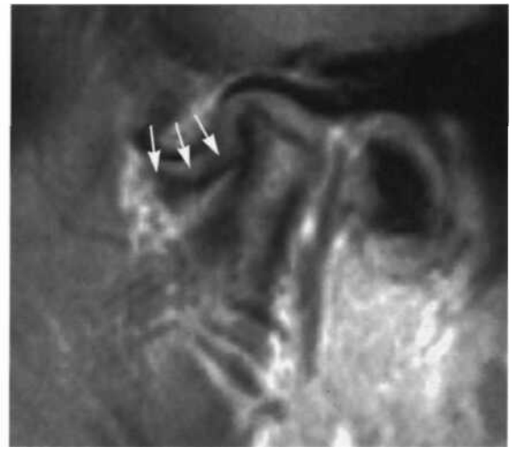
Right: For this reason, arthrography is not indicated for disk perforations.



168 Osteoarthrosis/osteoarthritis and disk perforation
Left: Disk perforations in combination with degenerative changes in the joint surfaces occur frequently in the center of the disk or in the bilaminar zone.

Right: During jaw opening under compression there will be intensified rubbing sounds, possibly accompanied by increased pain. In many cases the disk perforation (blue) cannot be satisfactorily diagnosed. However, this is not necessary for treatment purposes.





169 Osteoarthrosis/osteoarthritis and disk displacement
Left Condyles with degenerative changes can exhibit many different forms. In a few cases like this the areas of bone damage are not associated with significant changes in position and shape of the disk (arrows).

Right: Severely deformed joints, however, are usually accompanied by disk displacement (arrows) or perforation. Regardless of the position of the disk, the inferior surfaces of disks are affected by degenerative changes almost three times as frequently (57%) as the superior surfaces (Kondoh et al. 1998).

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Conducting the Clinical Joint Surface Tests

Testing of the functional joint surfaces on the patient begins with active movements. For this the examiner, while either standing or sitting at the 12 o'clock position, places two fingers over each condyle and then instructs the patient to first protrude the lower jaw as far as possible and then make a maximal jaw-opening movement from the protruded position. During these movements both examiner and patient remain alert to any isolated grating sounds or grating sounds in combination with pain. As a rule, crepitus during protrusion comes from the temporal joint surfaces and crepitus during jaw opening from the condylar surfaces. These active movements serve as a base of reference for the following tests.

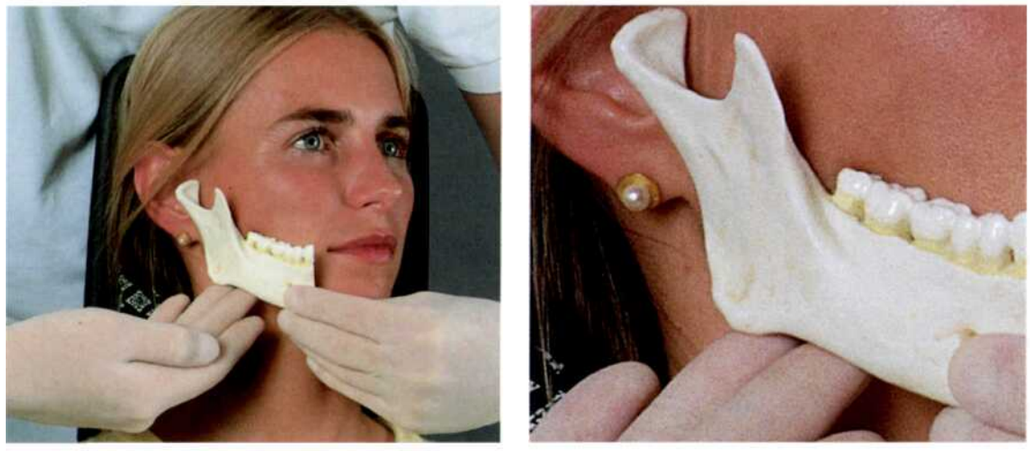
For the *dynamic compression test,* the examiner places two or three fingers under the angle of the mandible on each side so that neither the facial blood vessels nor the medial pterygoid muscles are significantly disturbed. The examiner now exerts a superior or anterosuperior pressure while the patient again protrudes and then opens to the maximum. Under physiological conditions, neither rubbing sounds nor pain will occur during the movements.

170 Active protrusion followed by jaw opening
Left: Active movements serve as a reference (control) for the dynamic tests. As the examiner palpates the condyles, the patient executes a maximal protrusive movement.

Right: From the position of maximal protrusion the jaws are then opened to the maximum. Both the examiner and the patient remain alert to any rubbing sensations that may arise, either with or without pain.

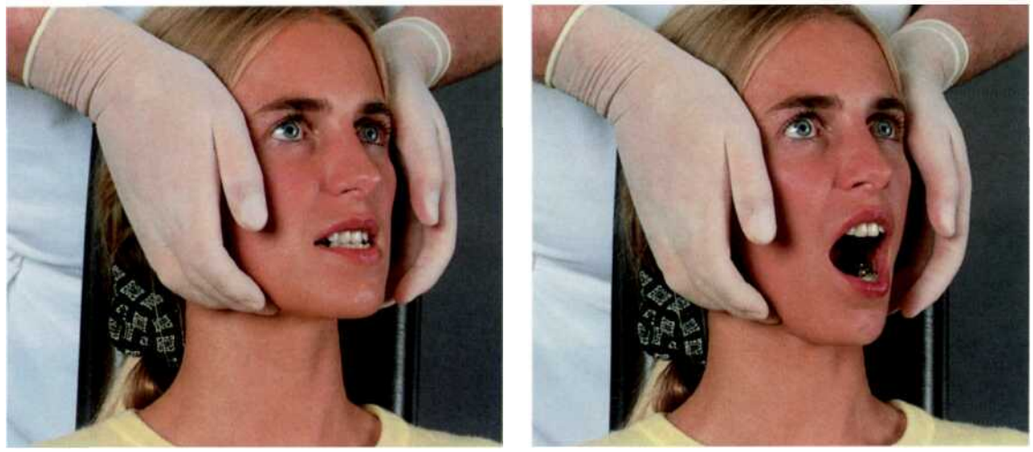
171 Positioning the middle and ring fingers at the angle of the jaw for performing dynamic compressions
Left: For dynamic compression two or three fingers are placed under the horizontal part of the angle of the mandible in such a way that the facial blood vessels and the insertion of the medial pterygoid muscle will be compressed as little as possible.

Right: Enlarged view showing the finger position at the angle of the jaw in greater detail.



172 Dynamic compression during protrusive and opening movements
Left: As the examiner presses superiorly or anterosuperiorly, the patient pushes the lower jaw forward as far as possible. Rubbing sounds that occur now usually arise from the temporal surface of the joint.

Right: Next, as the upward pressure is maintained, the patient opens the jaw as far as possible. Crepitus, pain, and any restrictions of movement that occur are recorded to help in making a differential diagnosis.



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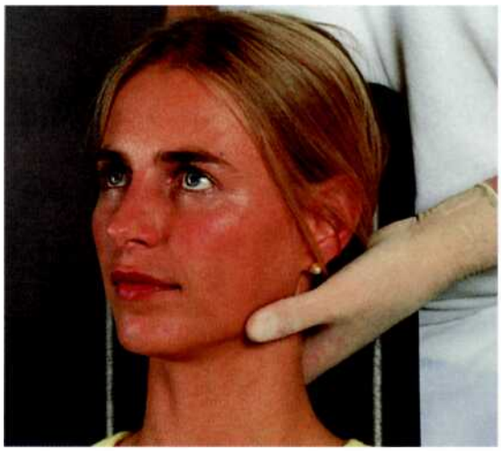
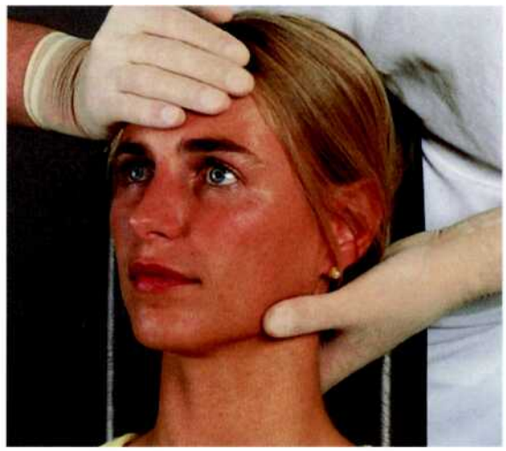
Crepitus during the protrusive movement indicates osteoarthrotic changes in the temporal joint surface, while crepitus during the opening movement points to changes on the condyle.

If dynamic compression provokes crepitus with pain (osteoarthritis) or crepitus without pain (osteoarthrosis), the examination is continued with *dynamic translations.* These can be conducted with or without manual compression. In this section of the book dynamic translation without compression is depicted, while the technique with the addition of compression can be seen on page 105.

Dynamic translations in the lateral and medial directions are specific for evaluating the lateral and medial portions of the joint surfaces. This is especially important when there is incongruence of the joint surfaces in the frontal plane. The parameters that can be distinguished by the dynamic tests are summarized below.

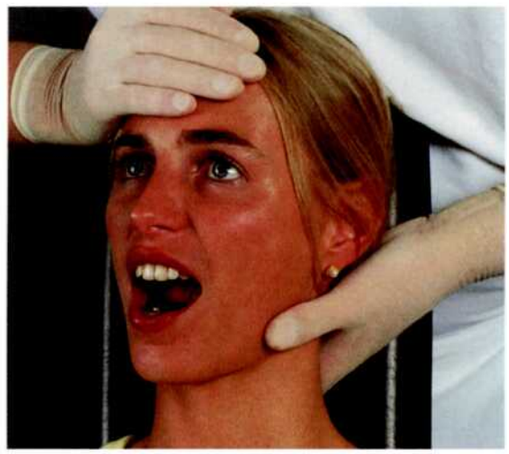
- *Osteoarthosis vs. osteoarthritis:* the tests either proceed painlessly or they elicit pain
- *Temporal vs. condylar:* symptoms appear either during protrusion or during jaw opening
- *Lateral vs. medial:* symptoms appear either during lateral or during medial translation.





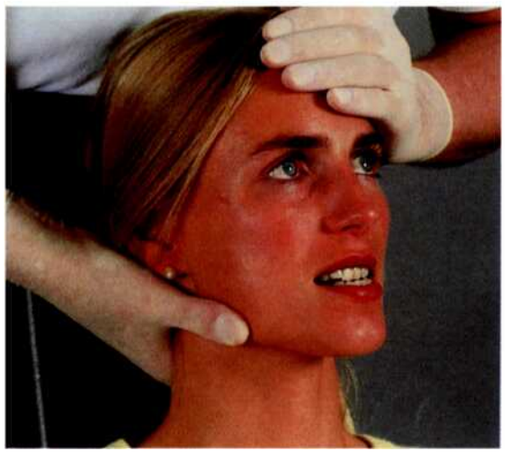
173 Hand position for dynamic translations
Left: To stabilize the head, one hand is placed flat against the back of the patient's neck. This also stabilizes the cervical spine. The thumb is placed at the level of the angle of the mandible.

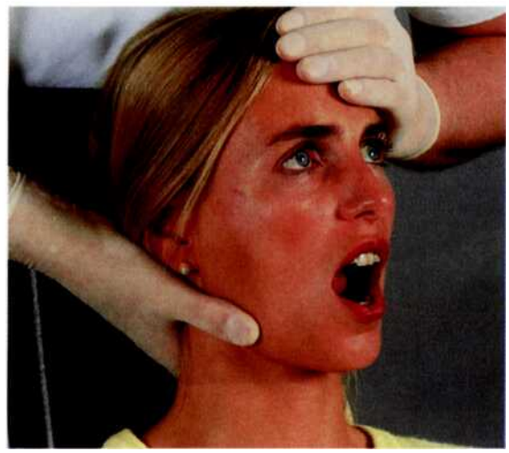
Right: The other hand braces the forehead from the opposite side. Now a force can be applied by the thumb medially toward the contralateral jaw angle. The result is a medial translation of the left condyle and a lateral translation of the right condyle.



174 Dynamic translation of the mandible to the right
Left: The translational force is continued as the patient moves the mandible forward as far as possible. The examiner has the patient repeat the movement until a clear determination can be made. This tests the integrity of the lateral joint surfaces in the right joint and the medial surfaces of the left joint.

Right: From the position of maximal protrusion the patient makes a maximal opening movement, and any rubbing sounds that occur are recorded.





175 Dynamic translation of the mandible to the left
Left: The examination procedure is repeated in a similar mannerforthe opposite side. After the head is stabilized at the neck and forehead, pressure is applied to move the mandible bodily to the left. The protrusive movement tests the medial joint surfaces on the right side and the lateral joint surfaces on the left.

Right: Finally the patient makes a maximal active opening movement from the maximal protrusive position.

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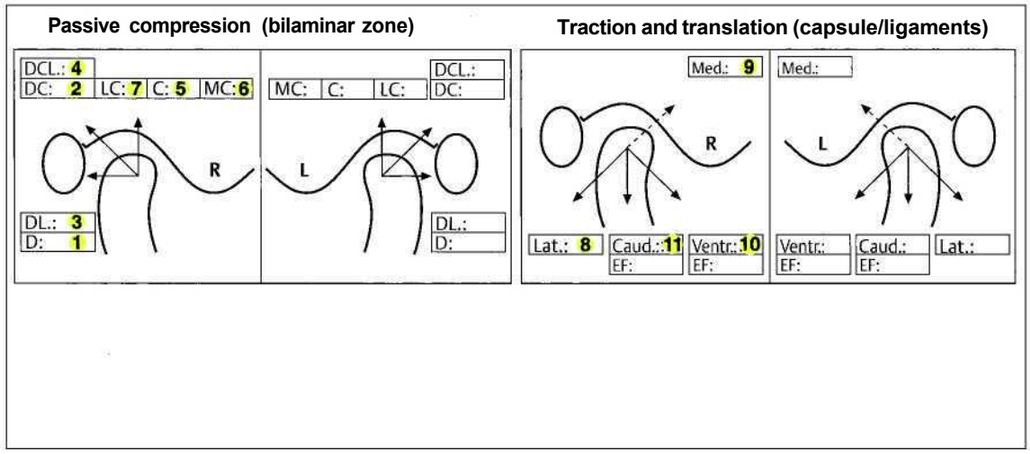
Examination of the Joint Capsule and Ligaments

Following the joint surface tests, those patients who have been experiencing pain are always examined further using joint manipulation techniques. Like all orthopedic examination techniques, these can be traced back to the fathers of manipulative medicine, J Cyriax, F Kaltenborn, G Maitland, and J Mennell (Cookson and Kent 1979). The specific joint manipulation techniques for orthopedics were first described by Mennell (1970). Hansson et al. (1980) were the first to recommend their use on the temporomandibular joint in dentistry.

The joint manipulation techniques consist of:
- passive compression,
- translation, and
- caudal traction.

In perspective, these are the most important clinical tests for the differential diagnosis of inflammatory changes in the joint region (Friedman and Weisberg 1982, 1984; Palla 1992; Riddle 1992; Bumann et al. 1993; Bumann and Groot Landeweer 1996b; Hesse 1996). Because there is no "gold standard" against which to measure results, their precise scientific verification is difficult (Hesse 1996).



176 Form for recording the findings of the joint-play tests
Passive compression, translation, and traction are all included under the concept of joint-play techniques. Pain that can be repeatedly provoked is recorded with color coding in the appropriate box on the form. The various sections will be explained more fully on the following pages. The numbers indicate the sequence in which the steps are carried out

With passive compression the bilaminar zone is examined for poorly adapted areas. Translation and traction serve to test the capsule and ligaments.

The examination always begins with *passive compression* (Bumann and Groot Landeweer 1996b). The rationale of the examination is based upon elicitating pain by loading various joint structures in different directions. In healthy joints, these manipulations are never painful (Palla 1986, Bumann and Groot Landeweer 1992, Curl and Stanwood 1993, McNeill 1993, Hesse 1996), because under physiological conditions the lateral ligament, acting as a motion-limiting structure, prevents injury to the bilaminar zone.

However, if the lateral ligament becomes overextended, pain sensations can emanate from the bilaminar zone because of its rich innervation (Scapino 1991 a, b) or from various parts of the capsule. During passive compression the muscles of mastication are not active and are not loaded. Because the disk and the joint surfaces are not innervated, they can be ruled out as sources of pain that can be repeatedly provoked. Therefore pain that can be provoked through posterior (retrusive) and/or posterosuperior compression is evidence of inflammation in one or more areas of the temporomandibular joint (Palla 1992, McNeill 1993, Bumann and Groot Landeweer 1996b). The high level of diagnostic reliability of passive compression has been demonstrated in clinical studies (Lobbezoo-Scholte et al. 1994, de Wijer et al. 1995).

If the dynamic tests for evaluating a patient's joint surfaces produce pain, then no diagnostically useful information can be gained through applying superiorly directed pressure during the same appointment.

Pain patients are able to report current pain with relative exactness (Cousins 1989, Bell 1991, Stacey 1991, Hewlett et al. 1995) and their reports can be useful in making a differential diagnosis. Seven passive compression tests are available and these are carried out in a definite sequence for ergonomic efficiency. Following each manipulation the patient is asked if pain occurred and if so, whether it was the same as that previously experienced or if it was elicited only by the momentary loading. In this way, as with the joint surface problems, three conditions of the bilaminar zone can be described:

- *Adaptation* (condition green): no history of pain and no pain evoked by compression.
- *Compensation* (condition yellow): no history of pain, but pain can be provoked repeatedly by passive compressions.
- *Decompensation* (condition red): history of pain, and individual pains can be provoked by compressions.

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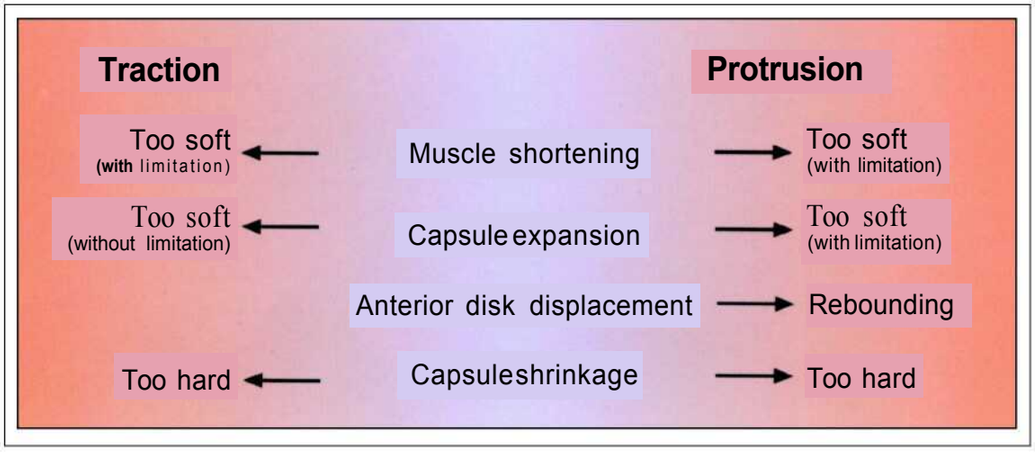
The three possible conditions of the tissues are noted in the patient's chart with color coding:

- All painful symptoms fall under the term *capsulitis* in the tissue-specific diagnosis.
- "Conditions yellow" are designated as *compensated capsulitis*
- "Conditions red" are designated as *decompensated capsulitis.*

Finally, the exact loading vector, which indicates the direction of compression, is added to the diagnosis. For example, a finding of "condition yellow" pain resulting from posterolateral compression would give the diagnosis: *decompensated capsulitis with a posterolateral loading vector.* In this case, during clarification of the contributing factors (see p. 124) we would look for one or more causes for the posterolateral force on the involved condyle.

- "Condition green" indicates either that the relationships in the bilaminar zone are physiological or that there is perfect adaptation to nonideal conditions. Even if the morphology is completely different from normal, there is no pressing medical indication for treatment. This has been confirmed over the long term through a series of basic studies (Pereira et al. 1996a, b).



177 Possible endfeels with traction and protrusion
Under physiological conditions the movements of the temporomandibular joint, with the exception of jaw closure, are limited by ligaments and therefore produce a "hard ligamentary endfeel." A number of structural changes can be responsible for different pathological endfeels. Above all else, muscle shortening and capsule shrinkage have the greatest therapeutic relevance because they can impose restrictions on the treatment.

After the bilaminar zone, the joint capsule and ligaments are tested specifically by means of translation and traction manipulations (Bumann and Groot Landeweer 1996b). These techniques serve on the one hand to determine if pain can be provoked, and on the other hand to evaluate the so-called "endfeel." There is a relatively high correlation between the findings by various examiners (de Wijer et al. 1995).

The specialized structure of the *ligaments* with their dense connective tissue and parallel collagen fibers provides high tensile strength (Gay and Miller 1978). Ligaments can be stretched by approximately 5-8% of their original length. This slight elasticity prevents irreversible damage to the ligaments themselves while still effectively limiting condylar movements and thereby protecting much more sensitive structures (Griffin et al. 1975, Sato et al. 1996).

The *joint capsule* exhibits fewer parallel fibers and is composed of different types of collagen. It is more elastic than the ligaments. The principle of collecting, documenting, and interpreting the signs and symptoms is exactly the same as for the passive compression tests. Pain within the joint capsule occurs only with inflammatory changes and is transmitted to the central nervous system by type-IV receptors (Wyke 1972, 1979; Clark and Wyke 1974). Various neuropeptides such as NA and SP effect the release of prostaglandins, which in turn elevate the sensitivity of the pain receptors (Levine et al. 1986, Lotz et al. 1987).

The *endfeel* is always tested in *anterolateral translation and inferior traction* when pain can be elicited in the opposite direction or when the mandible is to be therapeutically repositioned. The endfeel is the tissue resistance that the examiner perceives at the end of a movement. It depends exclusively upon the limiting structures. The physiological endfeel is "hard ligamentary" (Bumann et al. 1993). The possible pathological endfeels and their structural correlations will be discussed in greater detail on the following pages.

The capsule and ligaments can become shortened as the result of recurring inflammation or specific compressive functions (Haldeman 1989). Osteoarthrosis and osteoarthritis are frequently associated with shrinkage and reduced elasticity of the capsule (Stegenga et al. 1993). Hypomobility of the joint capsule, also called *functional joint compression,* may restrict treatment possibilities. *Failure to consider such restrictions makes treatment more difficult and often leads to an unstable result.* Capsule hypomobility can also increase muscle activity through the mechanoreceptors within the capsule, and therefore should be ruled out before any prosthetic treatment (Kraus 1994a).

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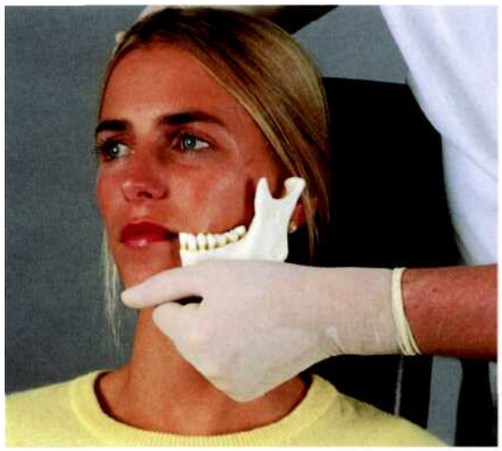
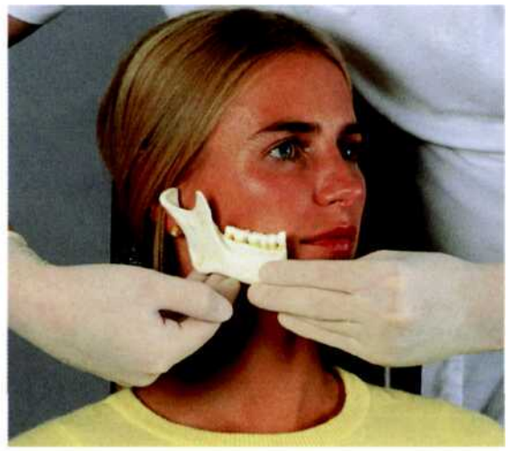
178 Hand grasp for passive compression

Left: The most frequently applied forces during passive compressions have a posteriorly directed component. To test the right temporomandibular joint the examiner applies a gradually increasing continuous pressure on the left side of the mental protuberance directed toward the right joint.

Right: To apply a superiorly directed component of force the fingers of the other hand are placed under the horizontal portion of the angle of the jaw.

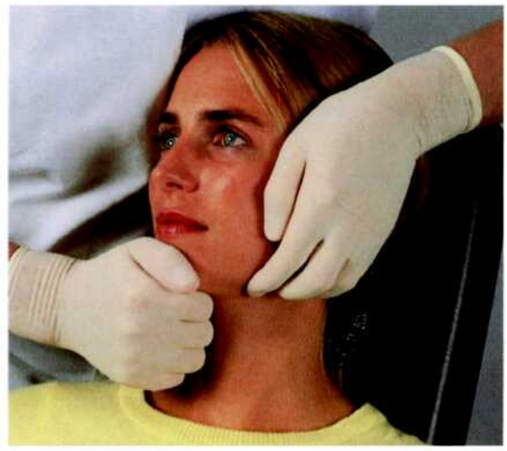




179 Posterior and posterosuperior compression of the left joint

Left: Application of posterior compression. Even with heavy pressure, this maneuver should not cause pain in a healthy patient. It can reliably demonstrate only inflammatory changes in the posterior direction.

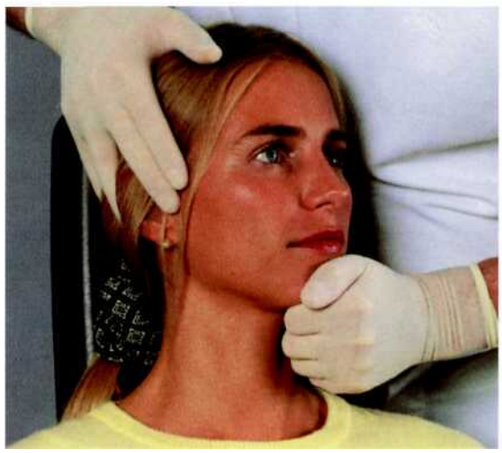
Right: For posterosuperior compression the action of the right hand is the same. The addition of an upward component by the left hand results in a posterosuperior loading of the joint.

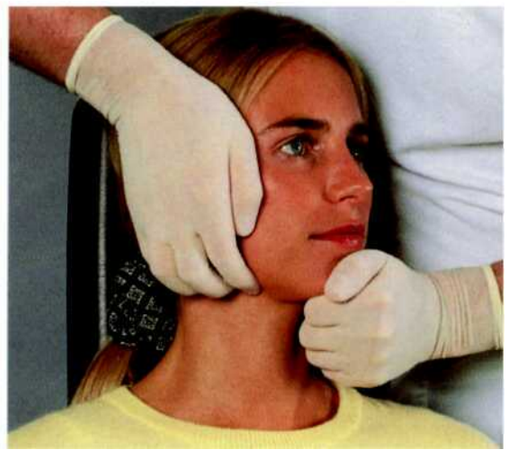


180 Posterior and posterosuperior compression of the right joint

Left: The left hand is used for posterior compression of the right joint. If the condyle is pushed back too quickly the lateral pterygoid muscle will contract (Gardener 1963). This reflex action is a mechanism to protect the sensitive joint structures.

Right: Posterosuperior compression of the right temporomandibular joint through simultaneous application of force with both hands.



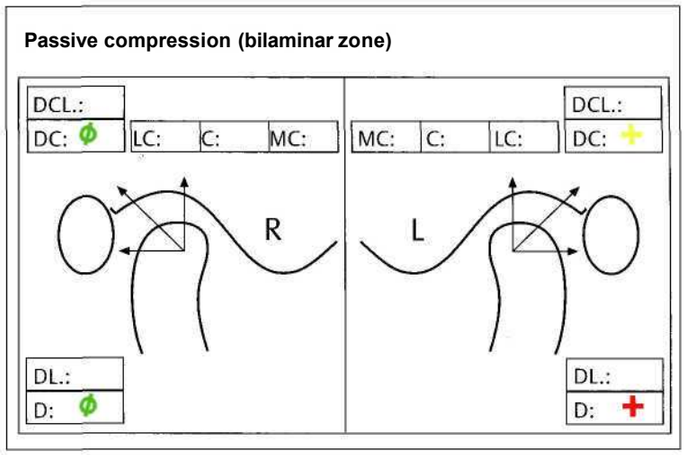


181 Examination form entries for posteriorly directed passive compressions

Right joint: Example of findings in a physiological or fully adapted condition.

Left joint: Compensated capsulitis with a posterosuperior loading vector and decompensated capsulitis with a posterior loading vector are recorded.

Because of their greater elasticity, joints of females can withstand greater loading than those of males (Loughneretal. 1997).



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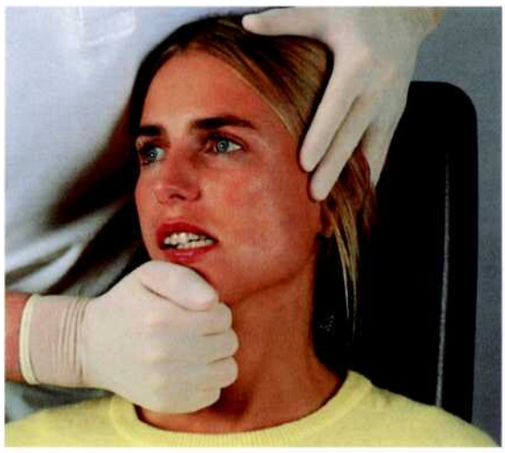
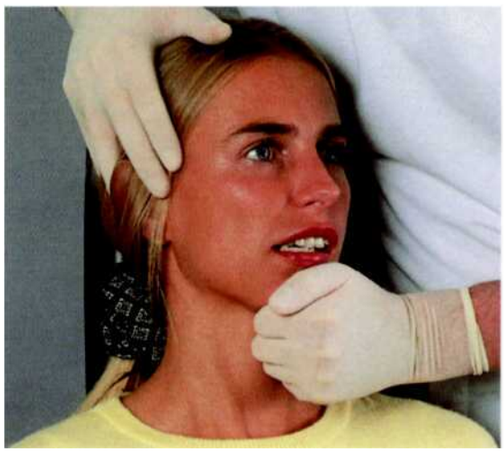
182 Starting jaw positions for posterior and posterolateral compressions
Left: The starting position for the previous passive compressions was with the mandible retruded and no tooth contact.

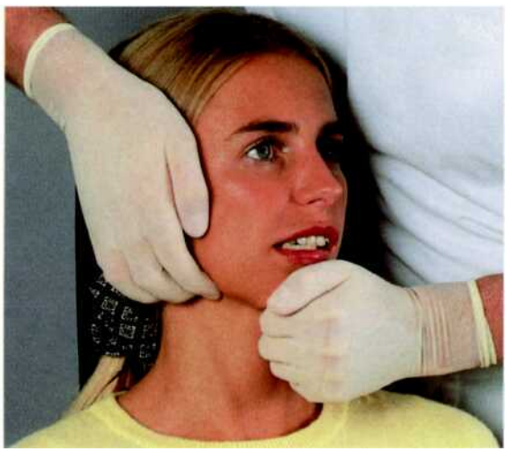
Right: For the following two compressions the patient assumes a position of maximal laterotrusion. This movement takes place with no forced guidance by the examiner. Force is applied only after the patient's jaw is in the starting position.



183 Posterolateral and posterosuperior compression of the left joint
Left: On the part of the examiner the same technique is used for the posterolateral compression as was used for the posterior compression. But because of the different starting position, the posterolateral portion of the joint is now being tested.

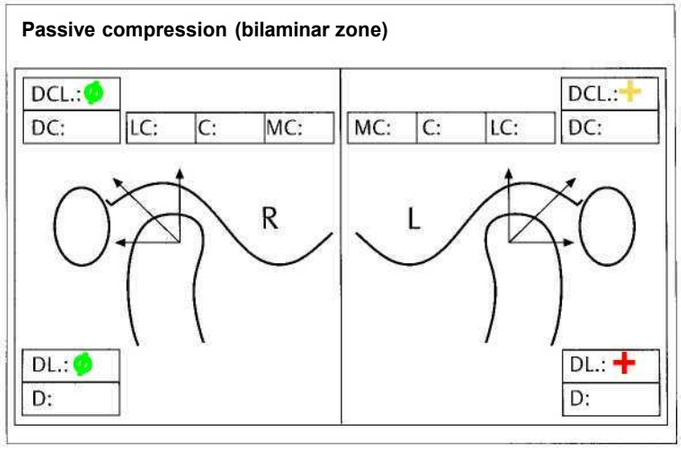
Right: During the posterosuperolateral compression the patient is responsible for the lateral starting position and the examiner for the posterior and superior components of force.





184 Posterolateral and posterosuperolateral compression of the right joint
Left: The right temporomandibular joint is examined in a similar manner, except that the posterior force is now exerted by the left hand while the patient holds the mandible in the maximal laterotrusive position for the right condyle.

Right: Posterosuperior compression of the right joint to evaluate the state of adaptation of the structures in this loading direction.



185 Chart entries for passive posterolateral and posterosuperolateral compressions
These sample entries indicate that the *right joint* is in either a normal or a completely adapted condition.
In the *left joint* a compensated capsulitis with a posterosuperolateral loading vector has been diagnosed.

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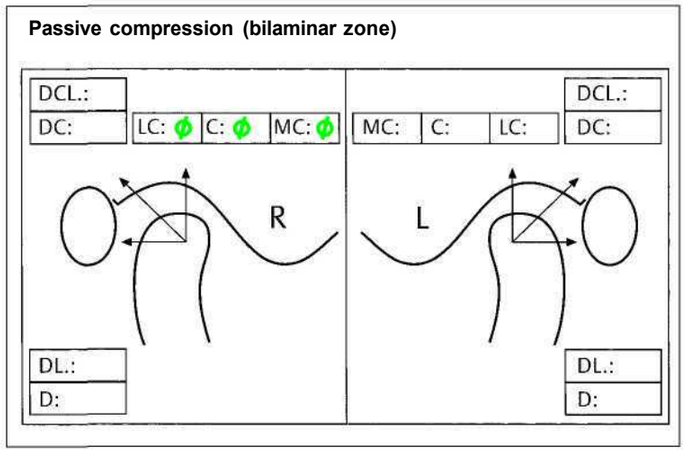
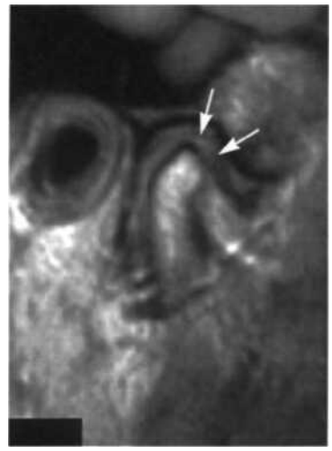
Clinical Significance of Compressions in the Superior Direction

The passive superiorly directed compressions (superior, laterosuperior, and mediosuperior) are especially important, not only for routine examinations but also for patients in pain, as they test the *state of adaptation of the bilaminar zone in the superior portion of the joint.* Positive findings always indicate a nonphysiological disk position. Because normally the pars posterior of the disk lies on the superior part of the condyle, which is not innervated, a correctly performed superior compression should not produce pain. But in cases with anterior disk displacement, the structures of the bilaminar zone lie over the superior part of the condyle when the teeth are in habitual occlusion. Unless the bilaminar zone is adapted (= fibrosed), superior compressions will provoke a painful response. Long-term clinical studies (de Leeuw 1994) plainly show that nonsurgical treatment is quite successful if the tissues are sufficiently adaptable. Therefore, clinical testing of the capacity of the individual patient's bilaminar zone to adapt is especially important in cases of disk displacement. The results of these tests carry a great deal of weight in deciding which therapeutic measures are indicated.

186 Reducing disk displacement with an adapted bilaminar zone
When the results of the superior compression tests are "green," either conditions in the superior portion of the joint are physiological or the bilaminar zone is well adapted. In either case there is no pressing need for treatment.

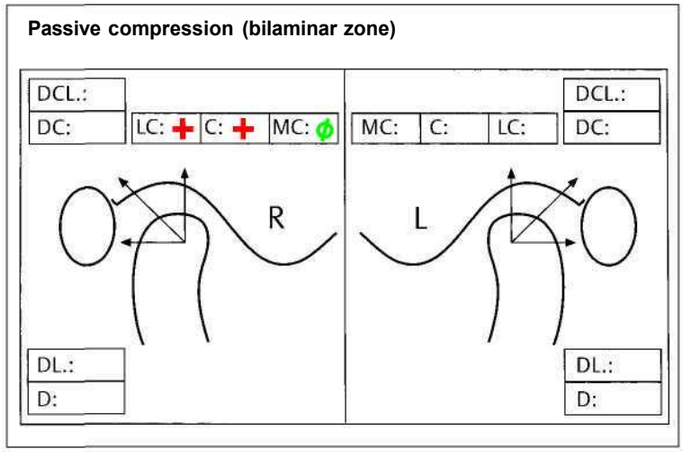
Right: MRI of a 17-year-old with anterior disk displacement and good adaptation in the cranial portion of the bilaminar zone, seen here as a dark gray signal (arrows).

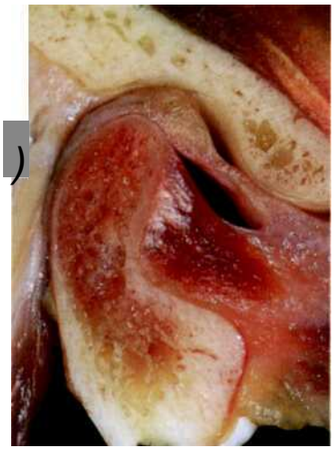




187 Tendency for anterior disk displacement
When there is a tendency for anterior disk displacement there will still be contact between the pars posterior of the disk and the anterior contour of the condyle. At this stage no clicking sounds can yet be detected. The superior portion of the bilaminarzone may be adapted, compensated, or decompensated. This example indicates laterosuperior (LS) and superior (S) decompensation and mediosuperior (MS) adaptation.

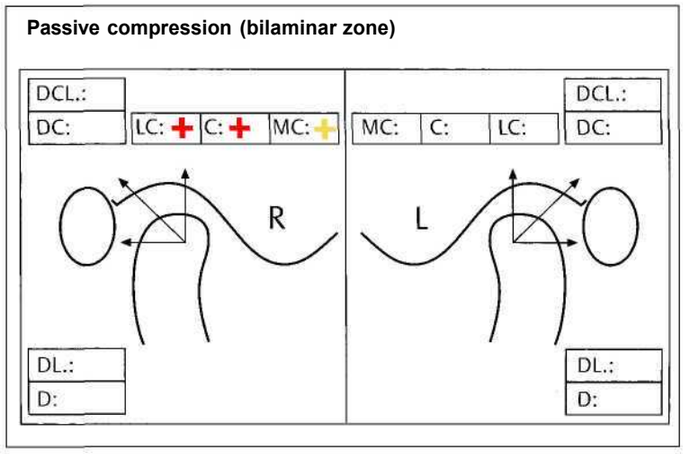
Right Macroscopic view of a joint with a tendency for anterior disk displacement.

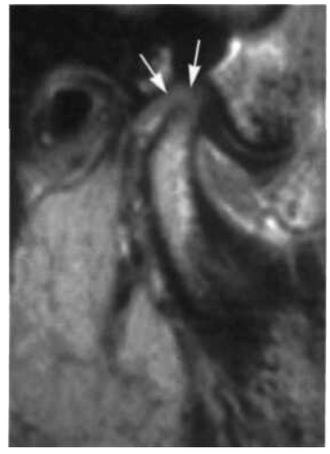




188 Nonreducing disk displacement
Findings in the superior portion of the joint of a 22-year-old patient with nonreducing disk displacement. The bilaminar zone has not adapted in any of the three directions. There is a compensated capsulitis with a mediosuperior loading vector and a decompensated capsulitis with superior and laterosuperior loading vectors.

Right: Anterior disk displacement in a MRI. The light-gray region indicates that there is no adaptation of the bilaminar zone (arrows).





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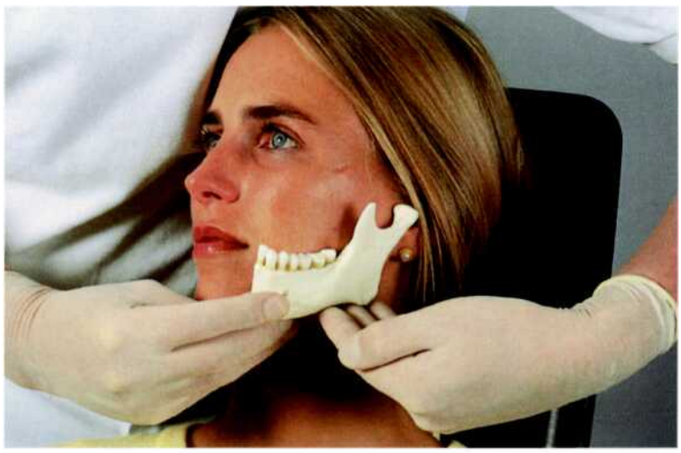
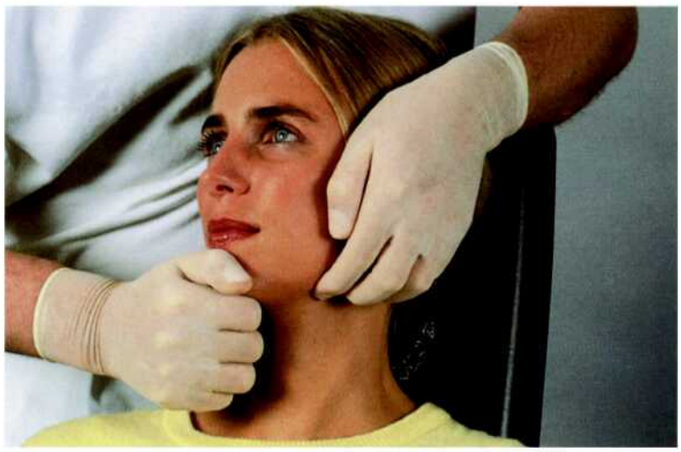
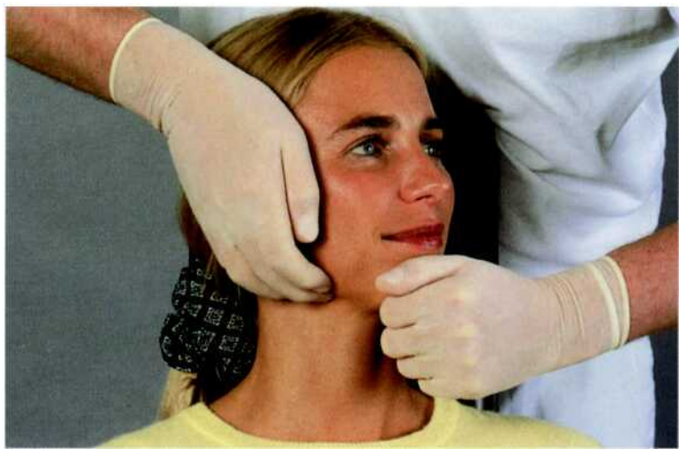


189 Hand grasp for superior compression
One hand is again placed under the horizontal part of the angle of the mandible. Great care must be taken to ensure that the force is applied exactly in the superior direction. Otherwise, false positive results could be obtained.

Left: An important condition for an efficient superior compression is the maintenance of an interocclusal distance. For this reason the examiner exerts a light downward pressure on the patient's chin with a thumb.

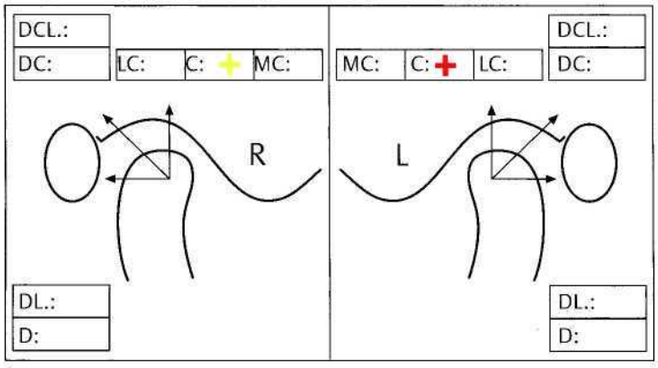


190 Superior compression of the left joint
The examiner's right hand helps prevent tooth contact while the left applies superiorly directed compression with a steadily increasing force. This test is never painful if the joint surfaces are healthy. If there is a painful response the technique should be repeated in a slightly protruded position. Only if pain can be repeatedly provoked in both positions is the code "yellow" or "red" entered in the chart.



191 Superior compression of the right joint
During superior compression of the right joint the examiner's left hand prevents tooth contact while the right hand applies a superiorly directed pressure. Pain indicates a nonadapted part of the bilaminar zone and a nonphysiological spatial relationship between disk and condyle. The possible diagnoses (tendency for disk displacement, reducing disk displacement, nonreducing disk displacement) have far-reaching implications for the treatment.

Passive compression (bilaminar zone)



192 Examination form
An example of entries of findings from superior compression. In different jaw positions a diagnosis was made of a compensated capsulitis with superior loading vector on the right side and a decompensated capsulitis with superior loading vector on the left side. In these cases the endfeel of inferior traction must always be tested to determine whether a constricted capsule is also present. If so, this would intensify the loading vector and make any relaxation therapy more difficult.

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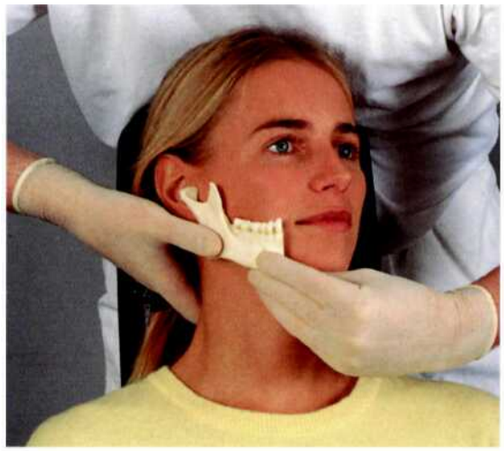
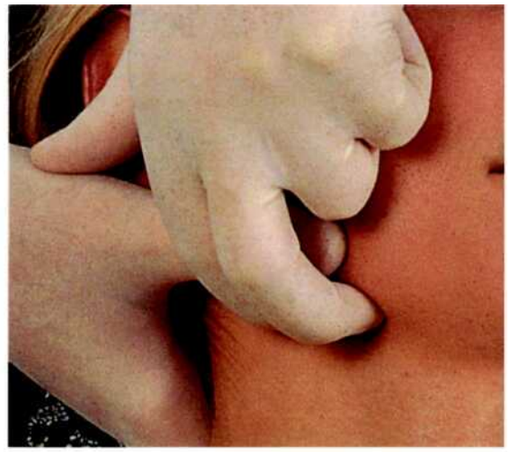
193 Hand grasp for medial and mediosuperior loading

Left: To apply the medial component of force the examiner places one hand flat against the back of the patient's neck and, with the thumb of the same hand, exerts a medially directed pressure against a broad area over the angle of the jaw. Here this results in medial translation of the right condyle and lateral translation of the left.

Right: To produce mediosuperior compression a superior component of force is added with the other hand.

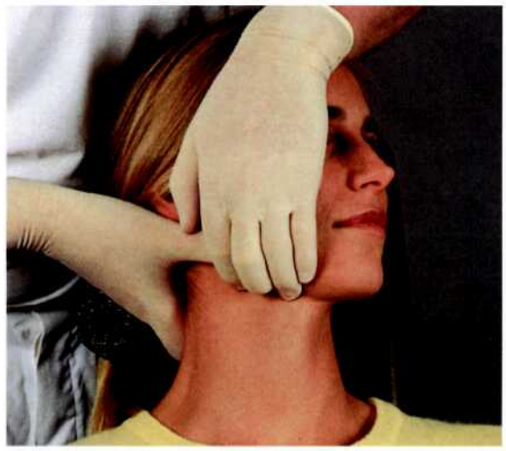


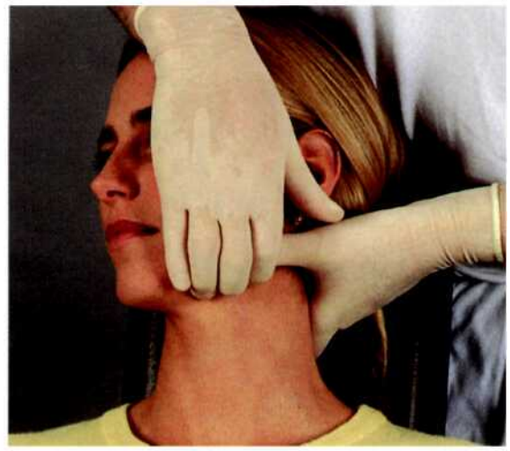


194 Mediosuperior compression right and left

Left: For mediosuperior compression of the right joint the medial component of force is provided by the examiner's right hand and the superior component by the left hand. This allows evaluation of the medial portion of the bilaminar zone.

Right: Mediosuperior compression of the left joint is accomplished by reversing the procedure. In this way the medial portion of the bilaminar zone in the left joint is tested.

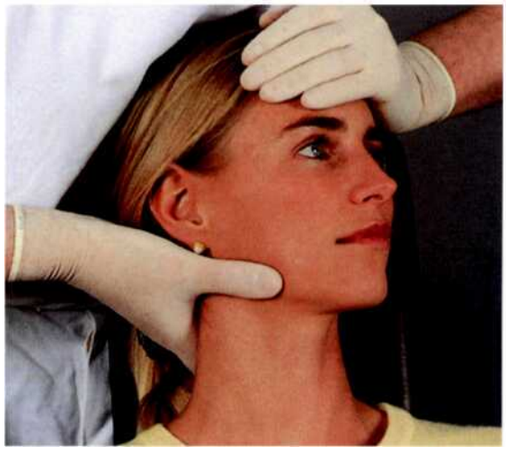


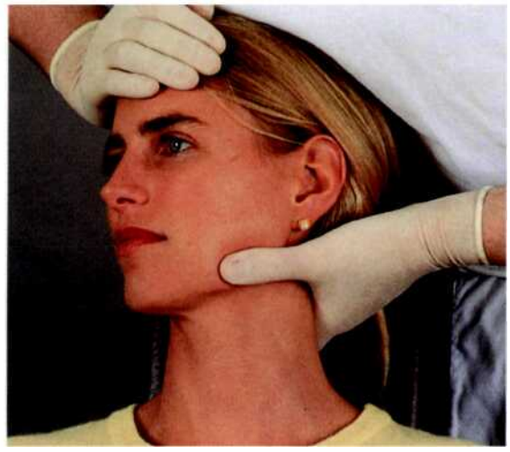


195 Medial translation of the right and left condyles

Left: The superior component of force is omitted for medial translation. This technique produces bodily movement of the right condyle directly toward the median plane with no mediotrusive movement! Only responses from the joint on the same side are recorded as no conclusions can be made about the contralateral side.

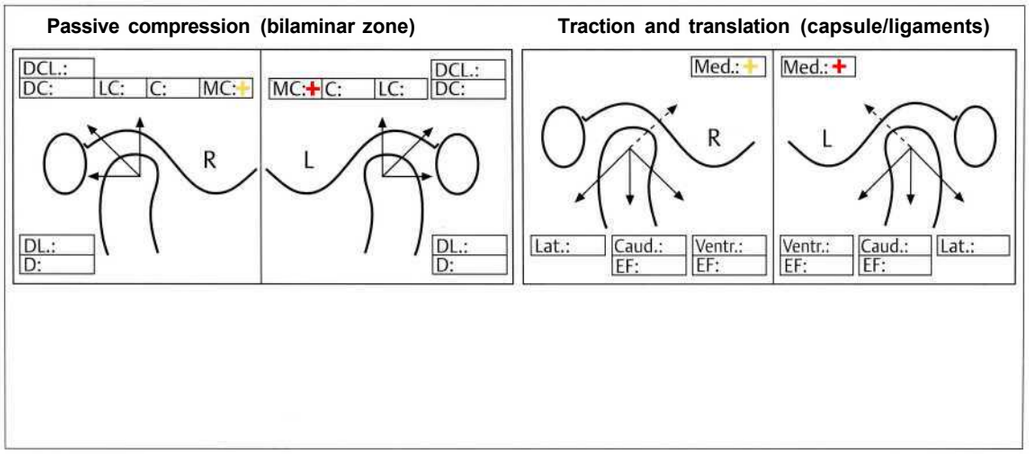
Right: Medial translation of the left condyle is accomplished by the examiner's left hand. Pressure is exerted by the thumb over a broad area of the angle of the jaw.





196 Examination form

The results of the mediosuperior compression tests are entered under the heading "Passive compression" and those of the medial translation tests under "Traction and translation." The sample record form indicates a compensated capsulitis with a mediosuperior loading vector on the right and a decompensated capsulitis with a mediosuperior loading vector on the left. In addition there is a compensated capsulitis with a medial loading vector on the right and a decompensated capsulitis with a medial loading vector on the left.



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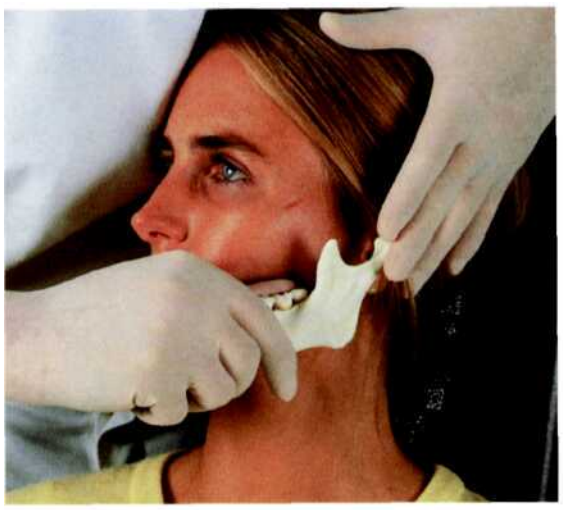
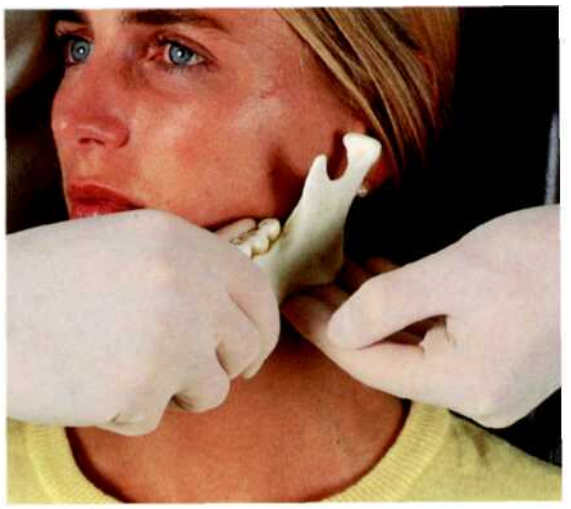
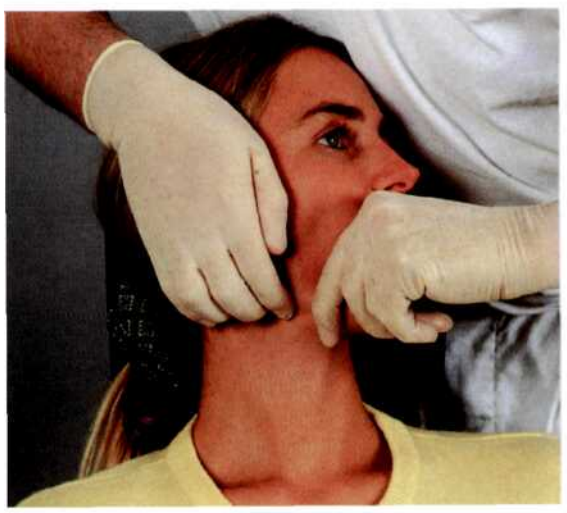
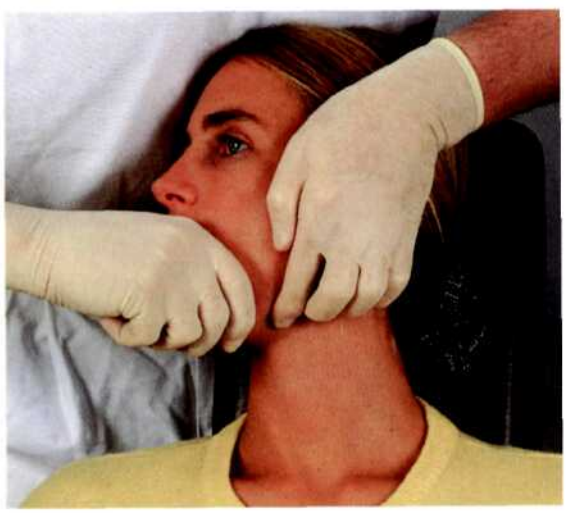




197 Hand grasp for lateral and laterosuperior loading
Left: The lateral component of force can be provided either by pressing inward on the angle of the jaw on the opposite side or by pressing laterally against the lingual surfaces of the molars on the side being tested. The latter method is more effective for monitoring the amount of translating movement through tactile sensation.

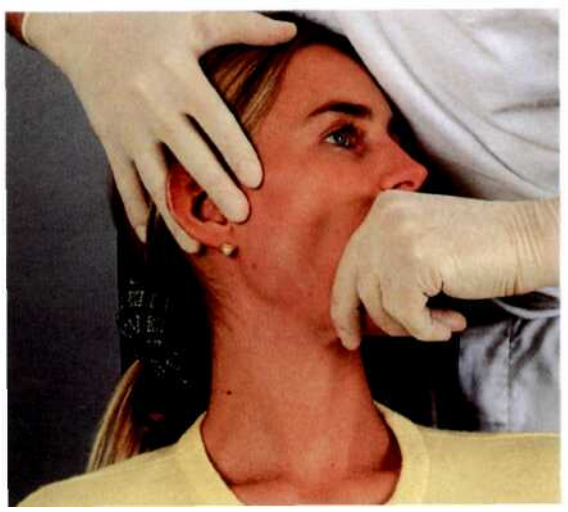
Right: The superior component of force is again maintained by pressure under the angle of the mandible.

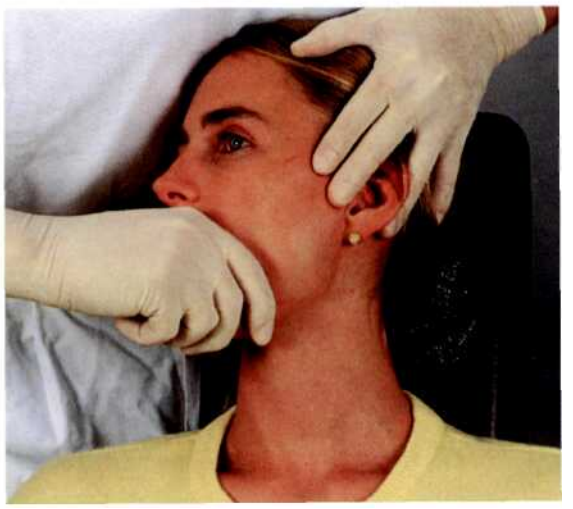




198 Laterosuperior compression right and left
Left During laterosuperior compression of the right joint the lateral component of force is exerted by the examiner's left hand and the superior component by the right hand. In this way the lateral portions of the bilaminar zone can be examined.

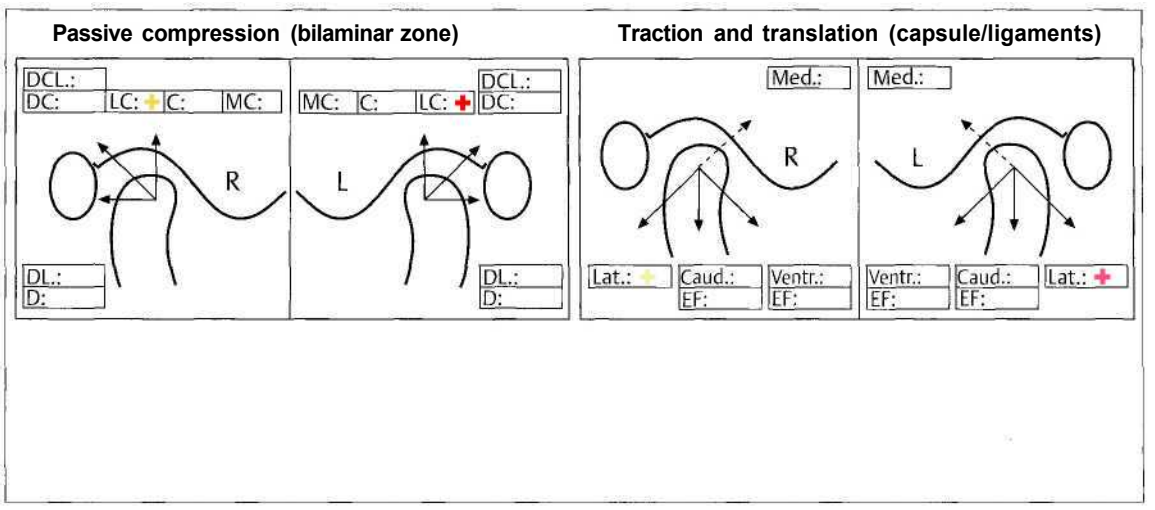
Right: The procedure is fully reversed for laterosuperior compression of the left joint. This allows evaluation of the lateral portions of the bilaminar zone in the left joint.





199 Lateral translation right and left
Left: For the lateral translations the superior component of force is omitted. With this technique there is movement of the right condyle toward the right side with no laterotrusive movement! Results are noted for the right side only and no conclusions can be formed about the contralateral side.

Right: The mandible is moved bodily to the left by the examiner's right hand.



200 Examination form
This example of a record form shows a compensated capsulitis with a laterosuperior loading vector on the right side and a decompensated capsuiitis with a laterosuperior loading vector on the left. Under traction and translation there is also a compensated capsulitis with a lateral loading vector on the right and a decompensated capsulitis with a lateral loading vector on the left.
An examination is always completed on one of the joints before the other side is examined.

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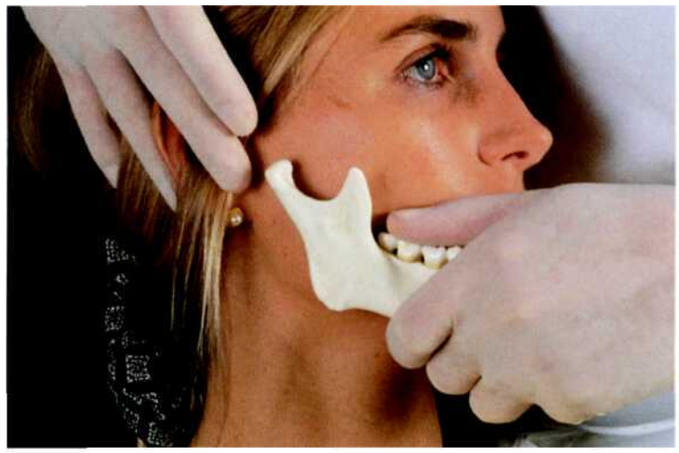
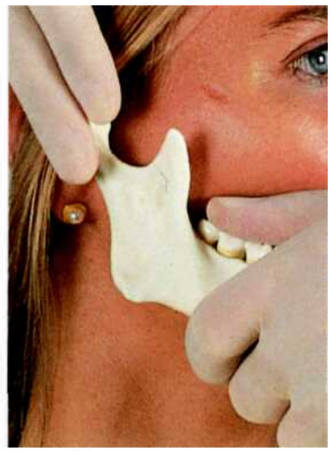
201 Loading direction for anterior translation
For anterior translation the thumb lies on the occlusal surfaces of the molars. The fingers wrap under the inferior border of the mandible without irritating the submandibular soft tissues. The jaw is pulled anteriorly but, because of the posterior slope of the articular eminence, this corresponds to an anteroinferior movement of the condyle.

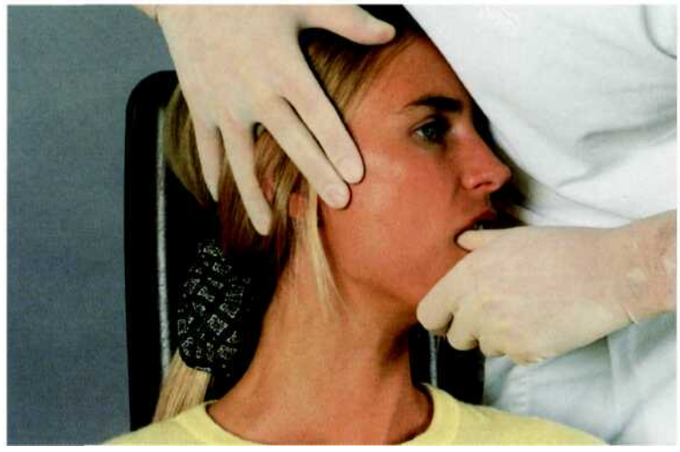
Right: Starting position for anterior translation with the patient's head stabilized.





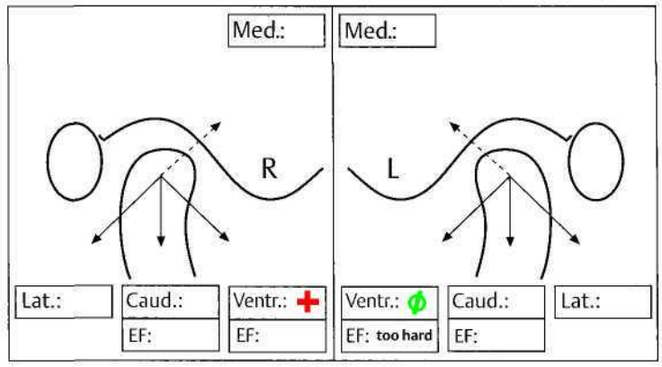
202 Anterior translation on the left side
Anterior translation is performed in conjunction with the medial and lateral translations. For evaluation of the left joint the examiner's left hand stabilizes the head while the right hand grasps the mandible. First the patient actively protrudes the lower jaw and then the examiner applies a continuous force in the same direction. This technique tests for the presence of provokable pain and the type of endfeel (hard ligamentary, too hard, too soft, rebounding, or bony).

203 Anterior translation on the right side
The anterior movement of the condyle can be followed by the fingers of the stabilizing hand. The endfeel can be evaluated only if the anterior translation is pain-free. If there is constriction of the capsule and the condylar position has been overcorrected (e.g. by a protrusion splint) this can result in increased tonus in the muscles of mastication (Clark 1976) and joint pain through activation of the type-IV receptors (Wyke 1972). In this case the pain can be relieved through mobilization of the capsule (Kraus 1994).



204 Examination form
Anterior translation provides valuable information for the diagnosis of pain and also evidence of any restrictions of movement that may be present. Here, for example, a decompensated capsulitis with anterior loading vector in the right temporomandibular joint is recorded. The endfeel could not be determined in this joint because of pain. Conditions on the left side are physiological or fully adapted. The left enfeel is too hard, indicating that there is a posterior pattern of function and that anteriorly directed treatment would be difficult.

Traction and translation (capsule/ligaments)



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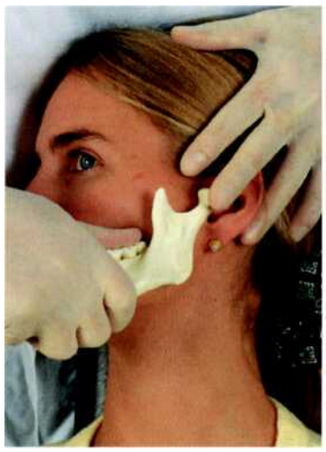
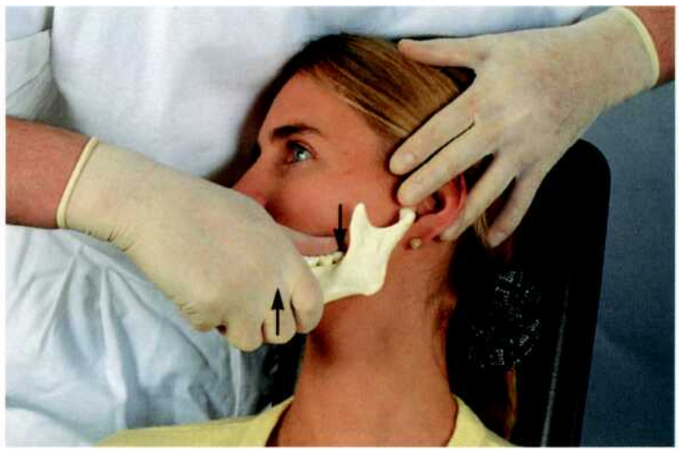
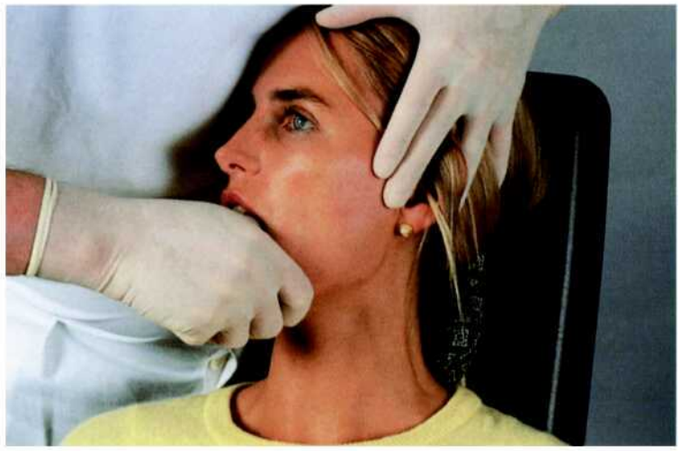


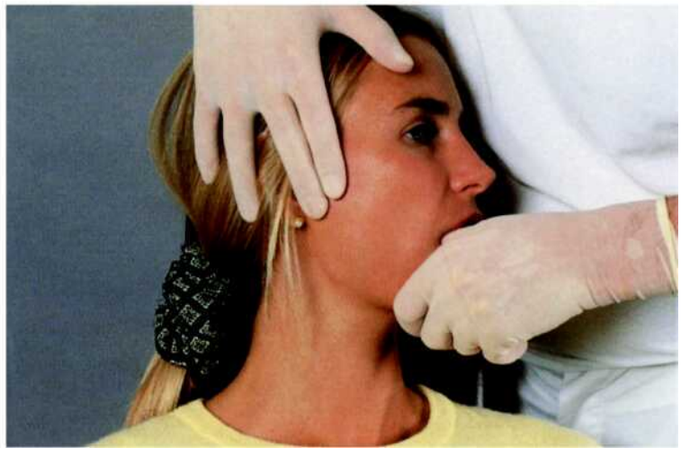


205 Direction of force for traction
A downward force on the molars and an even greater upward force on the border of the mandible at the chin produce a rotation which causes an inferior movement of the condyle. Contraction of the elevator muscles will not interfere with the inferior traction.

Left: The starting position for traction and inferior traction is identical to that for anterior translation. One hand grasps the mandible as the other stabilizes the head.

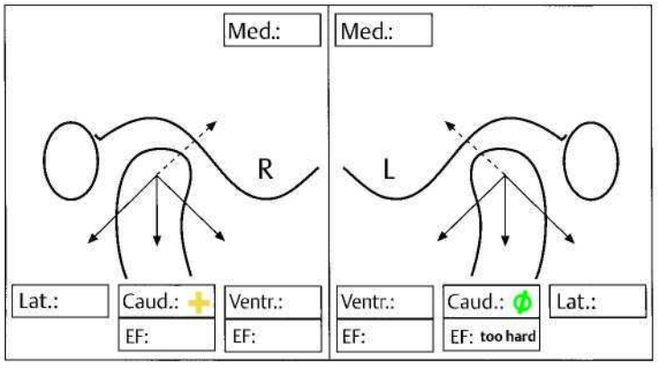


206 Inferior traction on the left side
To examine the left joint the examiner stabilizes the patient's head with the left hand and rotates the mandible in a clockwise direction with the right hand. This loads the entire circumference of the joint capsule. If the medial or lateral translation was painful, this traction should also be painful or the findings will not be conclusive. If traction does not produce pain, the amount of movement and the type of endfeel (hard ligamentary, too hard, or too soft) are recorded.



207 Inferior traction of the right joint
The procedure is carried out in a similar way for the right joint, except now the right hand stabilizes the head while the left makes a counterclockwise rotation. In this technique the mandible must not be rotated upward because that would not place traction on the capsule. The capsule and the lateral ligament are tested simultaneously. The medial wall of the joint capsule has no direct connection to the sphenomandibular ligament (Loughner et al. 1997) and therefore experiences no specific loading during traction.

Traction and translation (capsule/ligaments)



208 Record of findings
Traction is another important source of information for the diagnosis of pain. It also reveals any restrictions that might be present. The example here indicates thatthe right joint has a compensated capsulitis with an inferior loading vector. Because of the pain no determination of the endfeel in this joint could be made. In the left joint conditions are either physiologically normal or completely adapted. The endfeel is too hard, indicating a superior pattern of function and predicting difficulty in inferiorly directed treatment.

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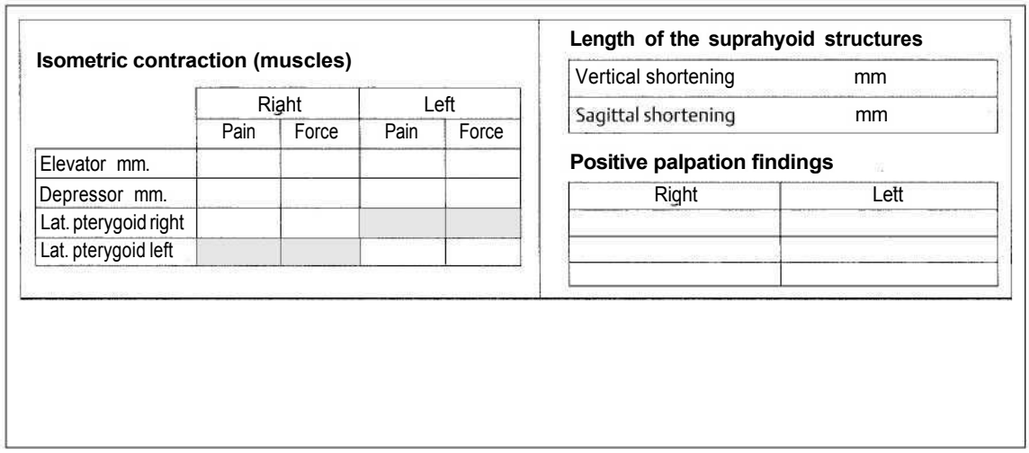
Examination of the Muscles of Mastication

The final step in the tissue-specific examination for patients in pain as well as for routine patients is testing of the muscles of mastication. As a rule, this involves identifying trigger points. *Trigger points* are defined as painful palpable areas of muscle that cause referred pain outside the anatomical boundaries of the affected muscle (Travell and Simons 1983, Simons and Mense 1998). In daily practice it has proven useful to identify reproducibly provoked pain in a particular muscle with the term "myofascial pain in the ... muscle" (Fricton 1990).

From a practical clinical point of view, pain in the muscles of mastication can be traced back to a compensation or decompensation of a joint problem or to endogenous hyperactivity of the central nervous system (Yemm 1976, Christensen 1981). According to more recent studies, however, hyperactivity of the motor cortex should be excluded as a primary cause for pain in the muscles of mastication (Cruccu et al. 1997). On the other hand, *changes in the sympathetic nervous system* do play an important role (McMillan and Blasberg 1994).

209 Testing the musculature
A section from the examination form concerned with testing of the muscles of mastication. Isometric contractions are used to detect painful muscle changes. If the findings are positive for pain, a specific palpation procedure is carried out to locate more precisely the area of muscle damage.
The lengths of the suprahyoid muscles are evaluated as part of the determination of any restrictions that may be present.



Isometric contraction (muscles)

	Right		Left	
	Pain	Force	Pain	Force
Elevator mm.				
Depressor mm.				
Lat. pterygoid right				
Lat. pterygoid left				

Length of the suprahyoid structures

Vertical shortening	mm
Sagittal shortening	mm

Positive palpation findings

Right	Left

The *elevators of the mandible* (jaw-closing muscles) include the temporal, masseter, and medial pterygoid muscles. In addition, the upper head of the lateral pterygoid is indirectly active in jaw closure. The *depressors of the mandible* (jaw-opening muscles) are represented by the lateral pterygoid muscle and some of the suprahyoid muscles, namely the geniohyoid, mylohyoid, and digastric muscles.

In a clinical examination two basic techniques are used to provoke muscle pain:

- muscle palpation
- isometric contractions.

When the reliability of these techniques for determining muscle signs and symptoms and their significance as a guide to therapy are discussed in the literature, it is often with more emotion than reason. It must be acknowledged from the results of controlled studies, however, that the results of *muscle palpation* are not satisfactorily reproducible for individual examiners and show little consistent agreement among different examiners (Viikari-Juntura 1987, Dworkin et al. 1990a, Cott et al. 1992, de Wijer et al. 1995, Borg-Stein and Stein 1996). Furthermore, the lateral pterygoid muscle cannot be palpated (Johnstone and Templeton 1980, Bertilsson and Strom 1995), nor can a large part of the medial pterygoid muscle.

For many years *isometric contractions* have been recommended on a trial basis as an alternative systematic functional test of the muscles of mastication (Cyriax 1947, Frost 1977, Hansson et al. 1987, Thomas and Okeson 1987, Groot Landeweer and Bumann 1991, Bezuur et al. 1989, Mense 1993, Gray et al. 1994, Okeson 1998). The following are some points that favor isometric contraction tests over palpation:

- A comparison study (Thomas and Okeson 1987) of the lateral pterygoid muscle clearly demonstrated that positive responses to palpation could be elicited in 27.6% of the subjects in a healthy control group, although none of the same subjects exhibited symptoms under isometric contraction. It follows from this that palpation resulted in a false positive diagnosis in 27.6% of healthy subjects.
- In the same study, muscle palpation gave positive results in 69.5% of a group of patients, but with isometric contraction, only 27.1% of the same patients tested positive. Thus the rate of false positive findings among patients was 42.4%!
- The inter-examiner agreement for isometric contractions amounted to 98.9%. The rate of this type of agreement for muscle palpation was not reported.

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Regardless of these scientific findings, it is important in treatment planning for the dentist to know if symptoms in the muscles of mastication can be provoked by palpation or only through functional loading. For example, the fact that no pain can be provoked in a muscle by isometric contractions, no matter how extreme, serves as clear evidence of pain-free function. If, in spite of this, pain can be repeatedly provoked in the same patient through palpation, one must first question whether the correct palpation technique was used and second whether a cause-oriented dental treatment is even indicated. This means that no treatment options remain for the dentist when there is absolutely no pain during the testing of muscle function. The various diagnostic muscle tests also help to clarify the controversy over the separation of craniomandibular problems into so-called arthrogenous and myogenous disorders. While some authors (Linde and Isacsson 1990, Wanman 1995) state the ratio of arthrogenous to myogenous problems to be 80 : 20, others (Jensen and Rasmussen 1996) find the ratio to be nearly reversed. Our own studies using systematic isometric contractions and joint-play tests indicate that approximately 80% of the symptoms reported by patients are clearly arthrogenous in origin.

Depressor muscles	Elevator muscles
Digastric muscle	Temporal muscle
Mylohyoid muscle	Masseter muscle
Ceniohyoid muscle	Medial pterygoid muscle
Lateral pterygoid muscle, inferior head	Lateral pterygoid muscle, superior head

210 Classification of muscles as primarily depressors or elevators of the mandible
As recent studies have again confirmed, the two parts of the lateral pterygoid muscle function as independent muscles (Bertilsson and Strom 1995, Aziz et al. 1998). The individual muscles of each type are tested as a group through isometric contractions. If necessary, painful areas can be further localized through palpation.

If, however, one designates every positive palpation response (pain, tension, hardening, hypertrophy) as a myogenous problem with no concrete reference to the pain reported in the patient's history, then approximately 80% of the craniomandibular disorders encountered in daily practice could be considered to be muscle problems. But because, in the final analysis, muscle changes are usually expressions of a compensation or decompensation for an arthrogenous lesion, they are often resolved simultaneously within the framework of arthrogenous diagnosis and treatment (Bakke and Moller 1992).

Isometric contraction tests have three significant advantages over palpation:

- Reproducibility = intrarater reliability (Malerba et al. 1993, Leggin et al. 1996).
- Objectivity = interrater reliability (Thomas and Okeson 1987, Lagerstrom and Nordgren 1998).
- Ability to test muscles that are inaccessible to palpation (Groot Landeweer and Bumann 1991, Okeson 1998).

The muscles should be held in a state of isometric contraction for 21-82 seconds, which approximates the techniques used in clinical experimental studies (Christensen 1981, Naeije and Hansson 1986). Painful muscle areas provoked by isometric and isotonic contractions can also be detected through MRI (Evans et al. 1998). This does not hold true for muscle pain elicited through palpation, however. Healthy test subjects were unable to provoke painful symptoms on themselves through isometric contractions on five successive days (Svensson and Arendt-Nielsen 1996).

The average maximum closing force in healthy subjects was 847 N for men and 597 N for women (Waltimo and Könönen 1993). Patients with muscle problems exhibited a *reduced closing force* during isometric contractions (Kroon and Naeije 1992). For this reason there is no reliable measurement of the force that can be developed by a muscle when it is painful.

In summary, an accurate evaluation of a painful muscle depends upon the magnitude of the force applied, the localization, the direction of palpation, the extent of surface contact, and the examiner's knowledge of the anatomy (Widmer 1994).

Injection of local anesthetic with vasoconstrictor into a skeletal muscle quickly leads to localized necrosis with complete regeneration within a few weeks (Benoit and Belt 1972). To minimize muscle damage, solutions containing vasoconstrictors and repetition of injections within a short time should be avoided (Benoit 1978). Because muscle relaxation can also be achieved by *transverse massage* (Gam et al. 1998), stretch *and cold spray* (Travell and Simons 1983), and postisometric muscle relaxation (Lewit and Simons 1984), these techniques are preferred over injections.

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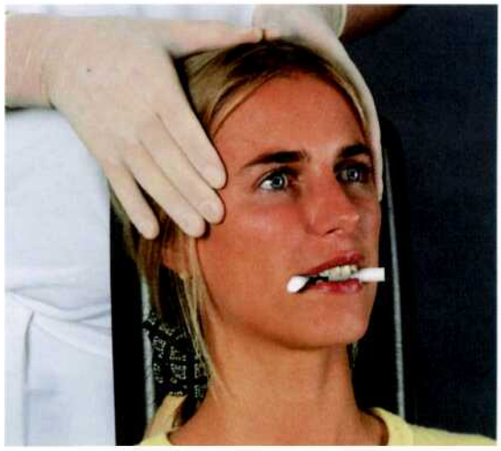
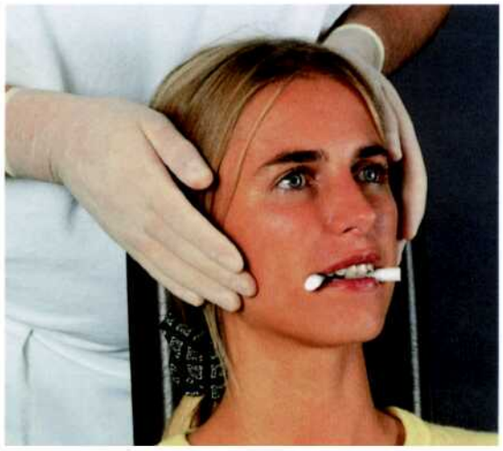
211 Isometric contraction of the elevator muscles
Left Extraoral view during isometric contraction of the elevator (jaw-closing) muscles. The duration of the contraction should be between 20 and 80 seconds.

Right: According to our own EMG studies, correct positioning of cotton rolls between the second premolars and first molars results in maximal loading of the elevator muscles.

212 Monitoring the contraction of the temporal and masseter muscles
Left: Verifying by feel the contraction of the anterior parts of the temporal muscles. As soon as any decrease in muscle tone is sensed, the patient is encouraged to continue the contraction. Only in this way can the examiner be assured that the muscles are being consciously loaded to the maximum for the intended period of time.

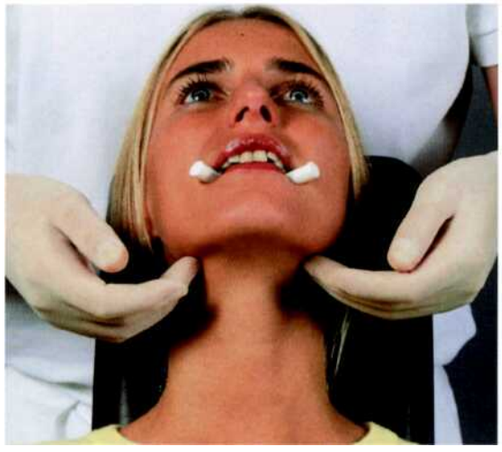
Right: Alternative monitoring of muscle contraction in the masseter muscles.





213 Monitoring contraction of the medial pterygoid muscles
Left: Testing for contraction of the medial pterygoid muscles. Following the contraction the patient is asked if, and exactly where, any pain was felt. The examiner must also ask if the pain is similar to that reported in the patient history or if it is an unfamiliar pain evoked only by the examination.

Right: A close-up view showing palpation of the inner side of the angle of the mandible.



214 Excerpt from the examination form
The results of the isometric contraction test are entered in either green (no pain), yellow (compensated myofascial pain) or red (decompensated myofascial pain). If pain is noticed only outside the anatomical boundaries of the muscles tested and outside the known regions of referred pain, no yellow or red entries are made in the chart. Basically, only muscle-specific findings are noted here.

Isometric contraction (muscles)

	Right		Left	
	Pain	Force	Pain	Force
Elevators	+			
Depressors				
Lat. pterygoid right				
Lat. pterygoid left				

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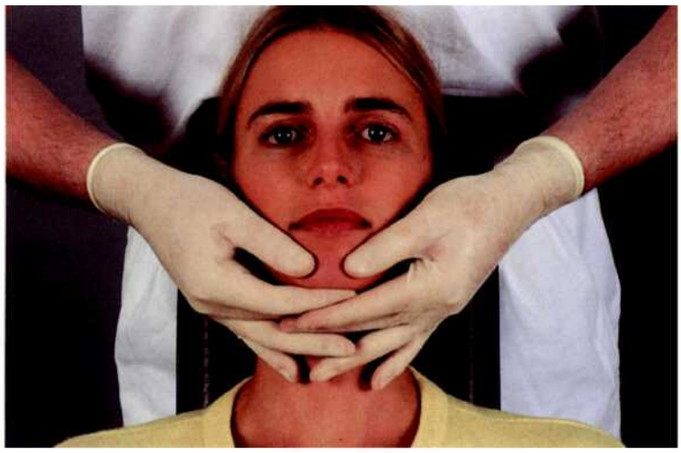
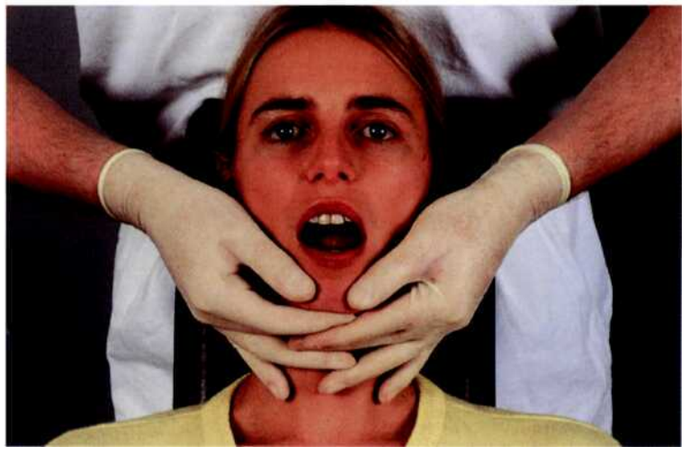


215 Isometric contraction of the depressor muscles
Right: Extraoral view during isometric contraction of the depressor muscles.

Left: Starting position of the mandible for isometric testing of the depressor muscles. If there was a painful response in the posterior range of passive compressions, all isometric contractions are carried out in a protruded mandibular position.

216 Isometrics with minimal jaw opening
As an alternative to the protruded mandibular position, isometric testing can be performed with the jaws slightly opened. While in the starting position the fingers are placed under the chin. The thumbs are used to provide additional support on the chin. Then upward pressure is built up for as long as the patient can withstand it. With a maximal force that varies from person to person, the patient must then offer resistance with the opening muscles for 20-80 seconds.



217 Isometrics with pronounced jaw opening
If isometric contraction is painful with the mandible in the protruded or minimally opened position, isometric testing can be attempted in a more widely opened position. If, however, passive compression produced painful symptoms in one of the superior regions of the joint, no conclusive information will be gained from isometric contractions because of interferences with the bilaminar zone. If this is not taken into consideration, false positive results will be recorded in a high percentage of cases.

Isometric contraction (muscles)

	Right		Left	
	Pain	Force	Pain	Force
Elevators				
Depressors	ϕ		+	
Lat. pterygoid right				
Lat. pterygoid left				

218 Excerpt from the examination form
Findings from isometric contraction of the depressors are entered in either green (no pain), yellow (compensated myofascial pain), or red (decompensated myofascial pain). If neither the elevators nor the depressors of the mandible are painful and if they exhibit normal forces, the tissue-specific examination is now concluded for patients with pain. The tests of the lateral pterygoid muscles described on the next page are performed only if the depressors give a positive response. Only muscle-specific findings are noted here.

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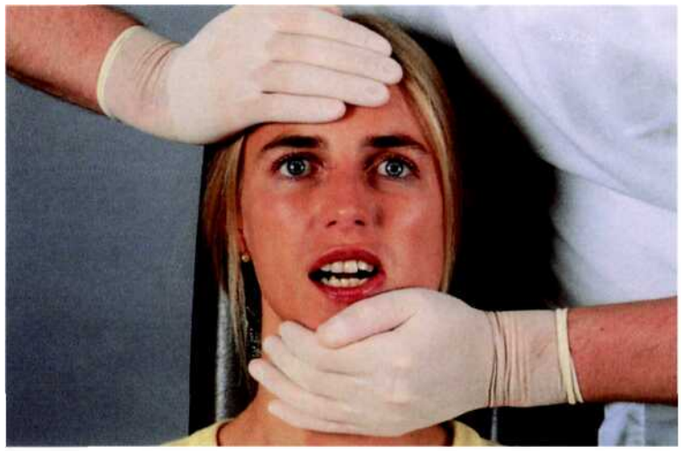
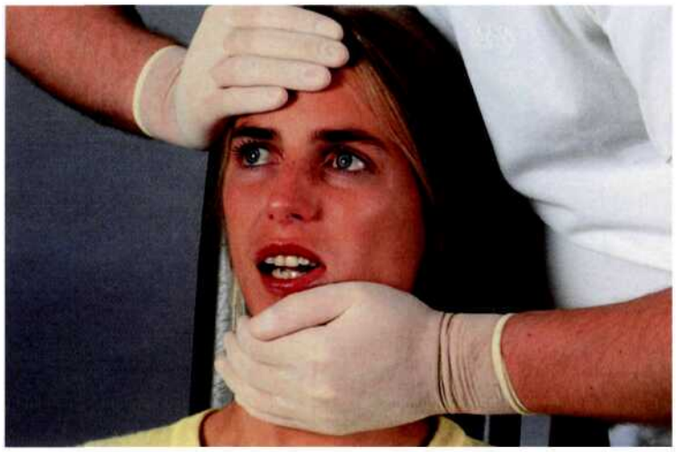
219 Isometric contraction of the lateral pterygoid muscles
When isometric contraction of the depressors produces preauricular pain, an isometric test is always performed on the lateral pterygoid of the affected side. If this produces the same pain elicited by isometrics of the depressors, there is myofascial pain of the affected lateral pterygoid muscle. If isometric contractions are painless, there is myofascial pain from the suprahyoidal musculature. From this point onward further differentiation can be made only through palpation.



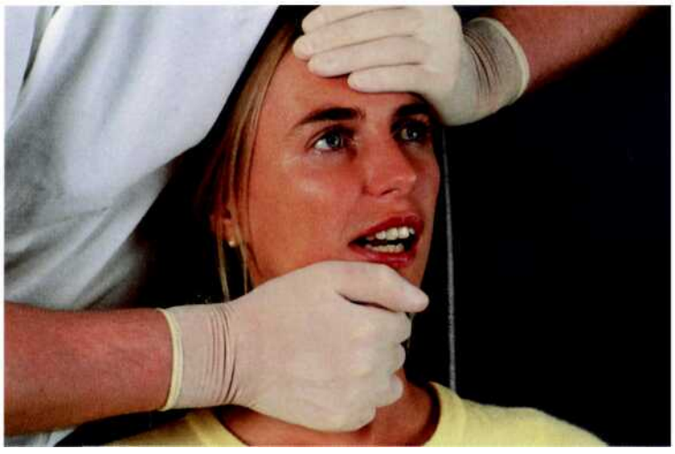
220 Isometric test of the right lateral pterygoid muscle
For an isometric evaluation of the right lateral pterygoid muscle it is also advisable to choose a joint-relaxing starting position. During the procedure the head must be well supported to avoid overloading the cervical spine.

Right: Starting position of the mandible for an isometric test of the right lateral pterygoid muscle. The bilaminar zone on the right side is relaxed by performing a mediotrusive movement.



221 Isometric test of the left lateral pterygoid muscle
Corresponding manual technique for an isometric test of the left lateral pterygoid muscle. The examiner pushes on the mandible toward the midline using a force that just balances the individual patient's maximum counter force.

Right: Starting position of the mandible for the isometric test of the left lateral pterygoid muscle. The bilaminar zone on the left side becomes relaxed by the mediotrusion.



222 Excerpt from the examination form
Some possible findings for the lateral pterygoid are shown recorded in the examination form. The sample entry for the right side indicates myofascial pain in the lateral pterygoid muscle (pain during isometric contractions of the depressors and the lateral pterygoid). The example for the left side records the finding of myofascial pain in the muscles of the floor of the mouth. The isometric test was positive for the depressor muscles, but negative for the lateral pterygoid.

Isometriccontraction(muscles)

	Right		Left	
	Pain	Force	Pain	Force
Elevators	ϕ		ϕ	
Depressors	+		+	
Lat. pterygoid right	+			
Lat. pterygoid left			ϕ	

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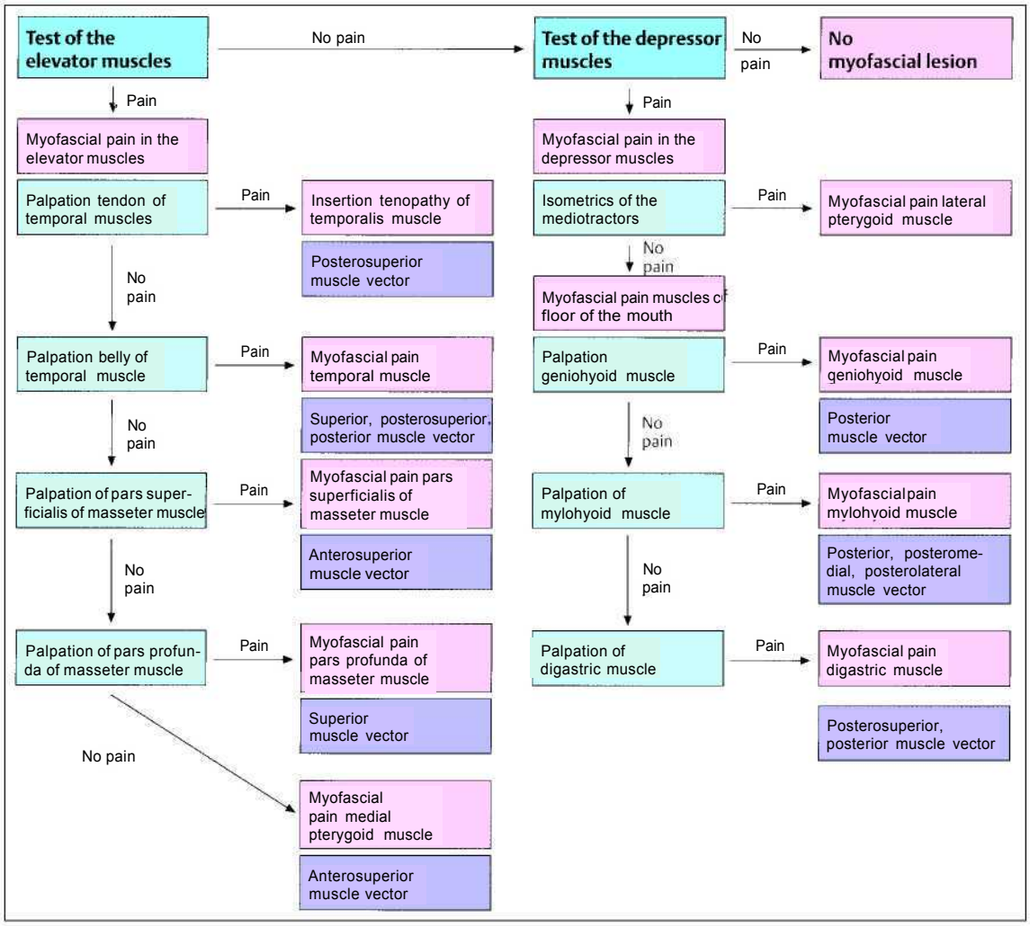
Palpation of the Muscles of Mastication with Painful Isometric Contractions

Palpation of the muscles of mastication for the differentiation of pain is indicated only when the response to isometric contractions is positive. The objective of palpation is the *precise localization of the muscle lesion* within a single muscle or in a synergistic group of muscles. If no specific local therapeutic measures for the muscle are being contemplated or treatment of the muscle problem is to be carried out by a physical therapist, palpation can be omitted even if there are positive findings from isometric contraction because the physical therapist would have to personally locate the lesion again in any event.

Specific palpation is usually accomplished by laying the palpating finger parallel with the muscle fibers to be tested. The actual palpating movements then take place at *right angles to the direction of the fibers.* In this way even lesions in different layers of a muscle, such as the pars profunda and pars superficialis of the masseter, can be reliably differentiated (Goulet et al. 1998). A force of approximately 40 N/cm2 should be used during specific palpation. This procedure results in greater discrimination than do a number of quantitative methods for detecting painful areas (Wolfe et al. 1990).



223 Schema of the palpation procedure with muscle-specific pain during isometric contraction
Normally, the muscles are palpated only if the results of the isometric contraction tests are positive. Unless muscle therapy or local anesthetic injection is to follow, in which case the exact location of the lesion would be meaningful, the muscle palpation tests may be deferred to be performed as part of the physical therapy, thereby avoiding duplication of examination procedures. The goals of palpation are to precisely locate the lesion within a functional muscle group (elevators or depressors) and to determine the exact muscle vector. Once the existing muscle vectors are known, tests must be performed to determine if there are joint related loading vectors in the opposite direction (see joint-play technique). If so, then this is certainly a case of compensation or decompensation and the muscle problem can be eliminated within the framework of joint therapy without additional expense.

Length of the suprahyoid structures

Vertical shortening	mm
Sagittal shortening	mm

Positive palpation findings

Right	Left

224 Excerpt from the examination form for recording the findings of muscle palpation
Positive responses to muscle palpation are noted in the appropriate boxes (lower portion) of the examination form. Only those findings that agree in quality and location with the findings of isometric contraction (= muscle-specific findings) are considered. Painful responses that are provoked only through palpation are disregarded.

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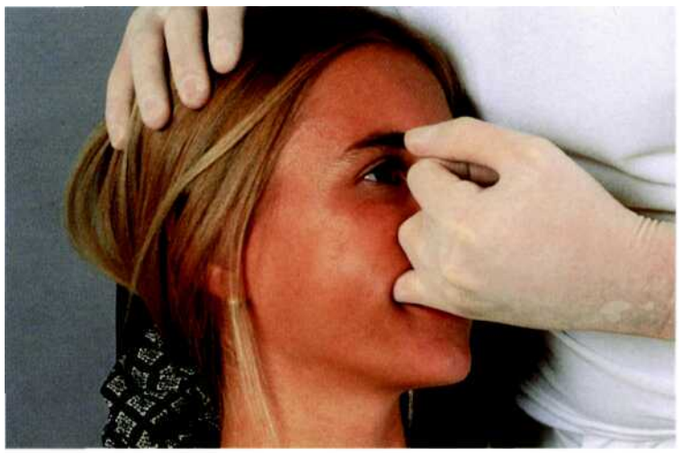
225 Palpating the lateral aspect of the tendon of the temporal muscle

The tendon of the right temporal muscle is best examined from the 1 o'clock position. This is done with either the little finger or the middle finger, depending upon the finger length required. Either the tip of the coronoid process or the lateral side of the retromolar triangle may be selected as the starting point (see Fig. 226).



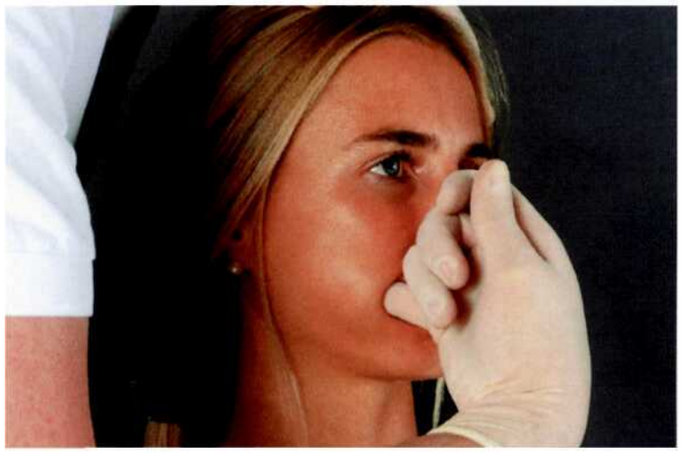
226 Position of the palpating finger

The ball of the little finger is used to palpate the tendon of the temporal muscle. If the isometric test of the closing muscles was positive and repeatedly elicited pain in the affected region, the entire lateral insertion of the temporal muscle must be palpated, not just one representative point.

Right: For the initial orientation one can locate the anterior border of the ascending ramus of the mandible lateral to the retromolar triangle.

227 Palpation of the medial aspect of the temporal tendon

In a similar manner the temporal tendon is examined on the medial side of the ascending ramus. For the right side, as shown here, the little finger of the right hand is used with the examiner in the 11 or 12 o'clock position. The objective of palpation is to provoke a response identical to that elicited during isometric contraction of the elevators. Other pains that may be provoked are of lesser significance.



228 Position of the palpating finger

The ball of the little finger of the right hand is used for palpation of the medial portion of the tendon of the temporal muscle. The anterior border of the ascending ramus is found by extending the line of the lower dental arch distally.

Right: The tendon insertion is then palpated along the medial side of the ascending ramus to the tip of the coronoid process. Palpation can be stopped as soon as the pain that was present during isometric contraction reappears.

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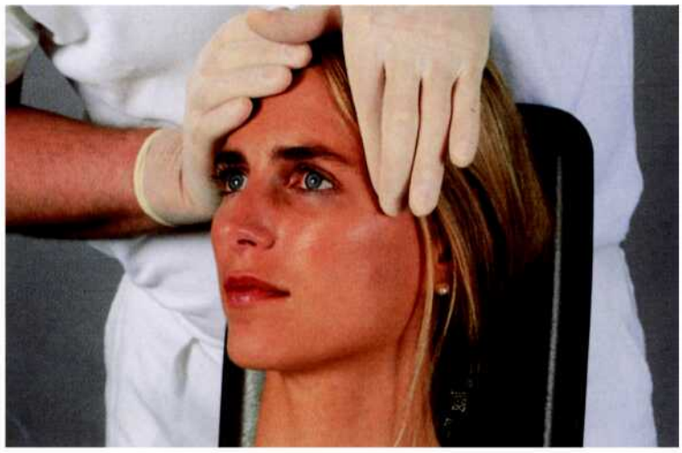
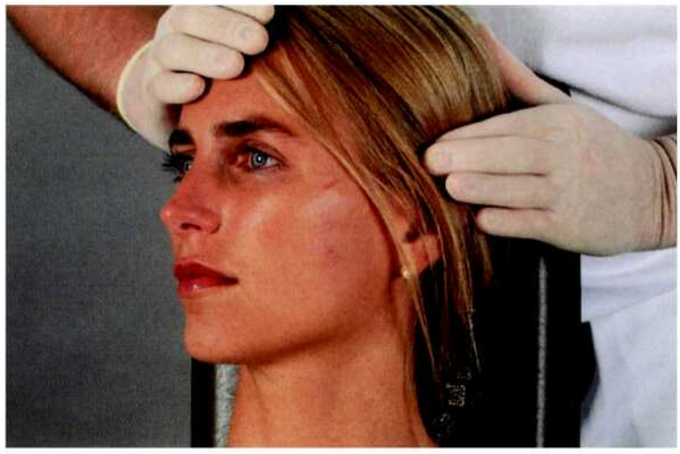


229 Palpation of the pars anterior of the temporal muscle
For palpation of the vertically aligned fibers of the temporal muscle the index finger is placed parallel with the muscle fibers to be examined. The actual palpation is done at right angles to the alignment of the fibers. Here too, palpation should reproduce the patient's specific pain. Sometimes palpation will precipitate a brief muscle spasm, the so-called local twitch response.

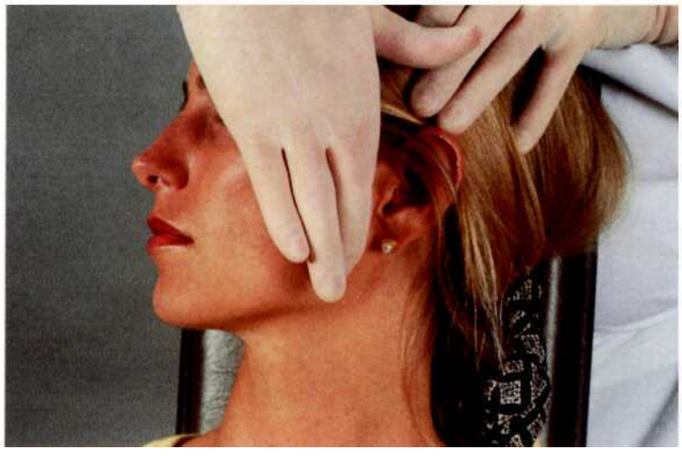


230 Palpation of the pars media and pars posterior of the temporal muscle
Right: Clinical view during palpation of the horizontal fibers of the pars posterior. Again, notice the angulation of the palpating finger.

Left: The pars media is palpated in a manner similar to that shown in Figure 229, except that the palpating finger is angled slightly more posteriorly. It is especially important for palpation of the broad muscles that the entire muscle be palpated and not just a few small points, as is frequently but erroneously described.

231 Palpation of the pars superficialis of the masseter muscle
Palpation of the masseter muscle is a classic example of a differentiated palpation at right angles to the long axes of the muscle fibers. Correct alignment of the palpating finger makes it possible to differentiate between lesions in the pars superficialis and lesions in the pars profunda.

Left: Anatomical specimen showing correct finger position for palpating the pars superficialis.



232 Palpation of the pars profunda of the masseter muscle
The pars profunda is tested with the finger in a more vertical position. If the lesion lies in an area where the two parts of the muscle overlap, the pain will usually occur only with one or the other directions of palpation. With a few patients, however, there will only be a difference in the intensity of the pain from the two directions of palpation.

Left: Anatomical specimen showing the correct finger alignment for palpating the pars profunda.

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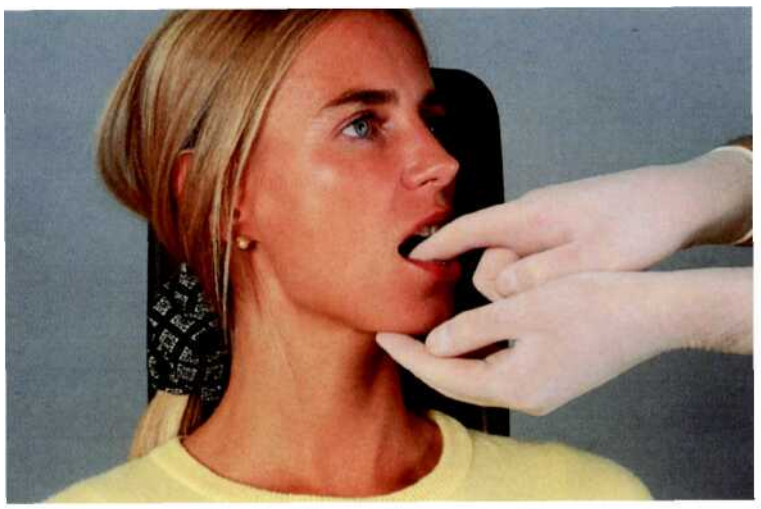
233 Palpation of the geniohyoid muscle—hand position

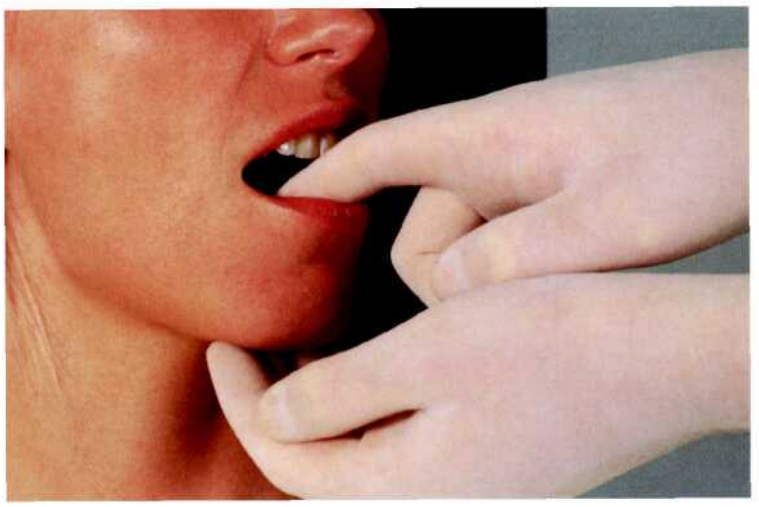
There are various techniques that can be used. The simplest and most consistent is the intraoral palpation with broad-based extraoral support. The index finger of the palpating hand is placed in the floor of the mouth parallel with the long axis of the geniohyoid muscle. Palpation is performed at right angles to the course of the muscle fibers. Less palpating pressure is used with the intraoral than with the extraoral techniques.

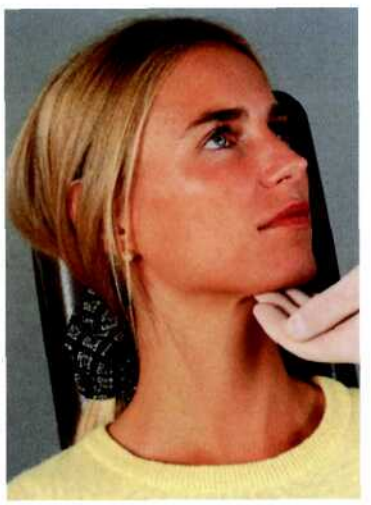


234 Palpation of the geniohyoid muscle—a mistake to be avoided

The fingers of the stabilizing extraoral hand should not be pressing with the tips as shown here, but should make flatter contact with the skin as in Figure 233. Otherwise false positive responses will frequently be obtained.

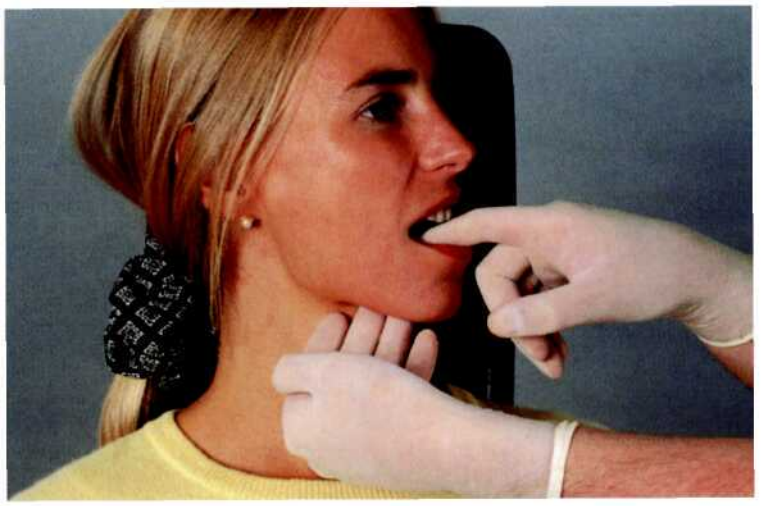
Right: Depiction of the wrong way to support the floor of the mouth. It should not be done this way!





235 Palpation of the mylohyoid muscle with support

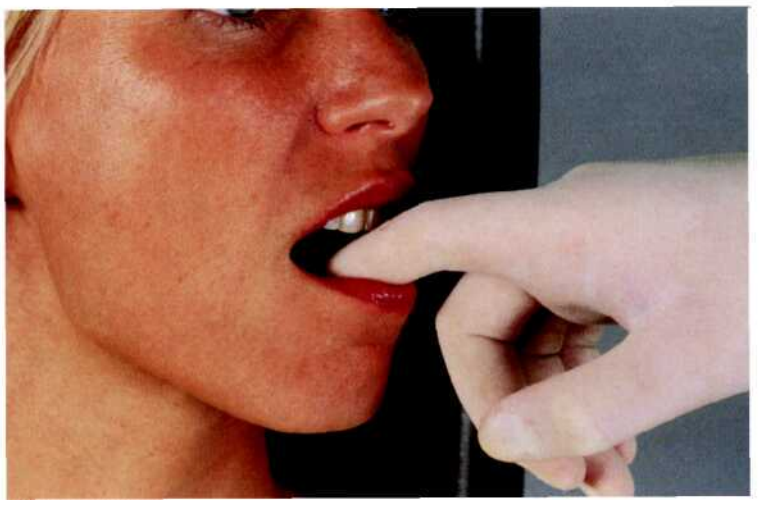
The mylohyoid muscles can be palpated intraorally while the opposite hand supports the floor of the mouth extraorally. The index finger of the palpating hand is positioned lateral to the geniohyoid muscle. In this area the anatomy is such that it is difficult to place the palpating finger parallel with the muscle fibers and so it is aligned perpendicular to them instead. Thus, in this case, the direction of the finger will also be the direction of palpation.

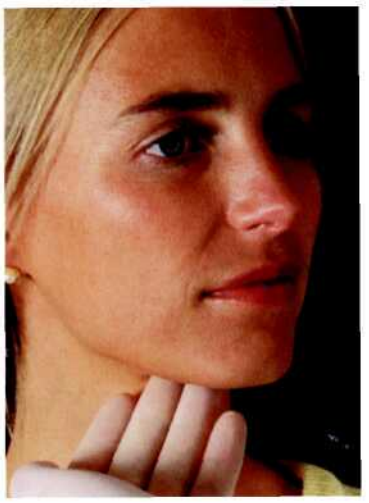


236 Palpation of the mylohyoid muscle without support

The mylohyoid muscle can also be palpated without extraoral support. In this method the position of the palpating finger is exactly the same as shown in Figure 235. Palpation is performed most efficiently from distal to mesial.

Right: In the extraoral technique the fingers of the palpating hand are placed at a relatively steep angle parallel with the direction of the muscle fibers. Palpation then takes place in a mesial or distal direction.





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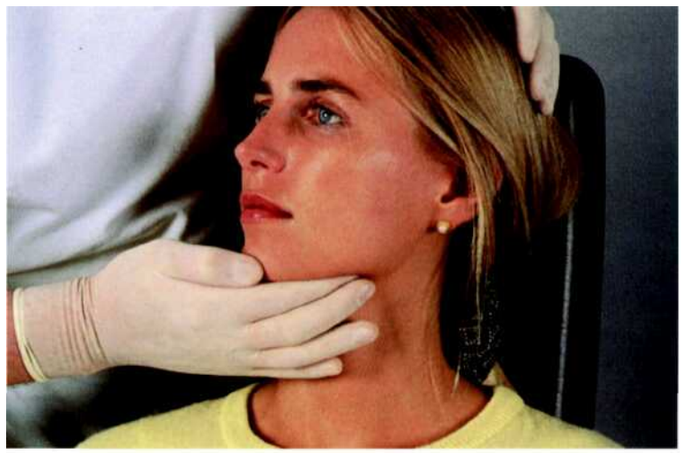
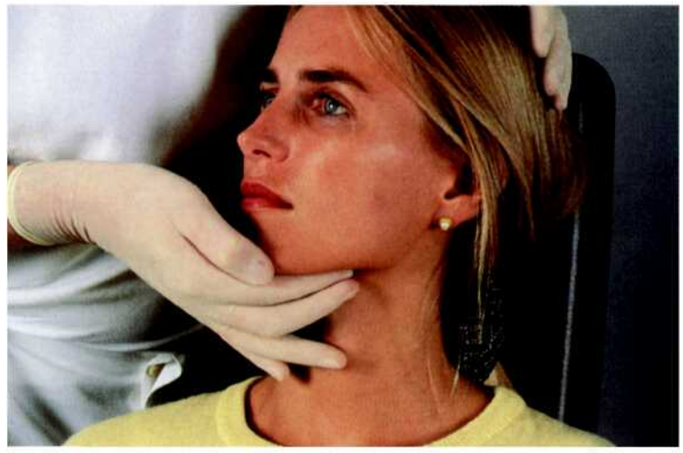
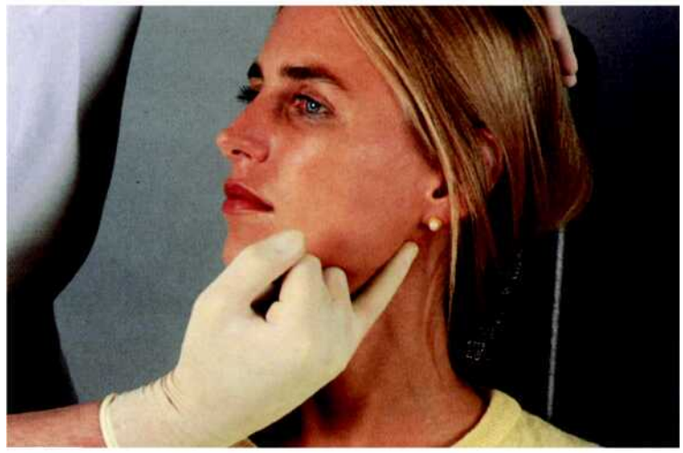


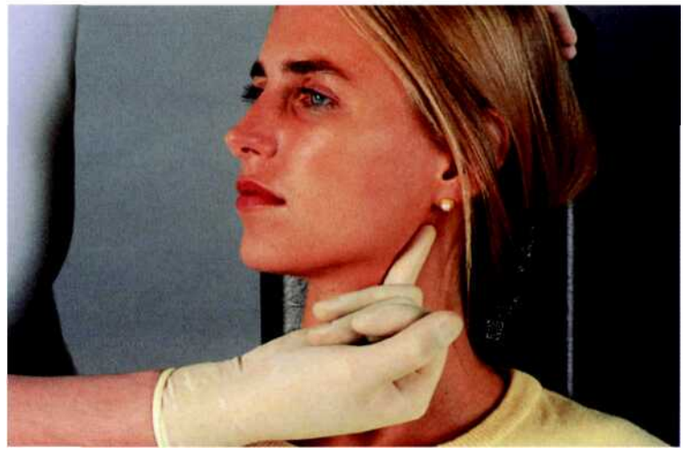
237 Palpation of the anterior belly of the digastric muscle
The palpating index finger is placed extraorally parallel with and directly beside the muscle. We have found that having the patient swallow makes it much easier to locate the muscle at this stage. The act of swallowing makes the direction of the muscle clearly identifiable to the palpating finger. Figure 238 shows the actual palpation motion.



238 Palpation movement
Beginning at the position described above, the finger makes a rolling motion toward the median plane. Conscious muscle contraction by the patient is unnecessary and presents no significant advantage. As always, one should be able to reproducibly provoke the specific pains experienced previously during isometric contraction of the jaw-opening muscles. Other nonspecific pain responses are of only secondary significance.



239 Palpation of the posterior belly of the digastric muscle
The posterior belly is palpated in a similar manner. The palpating finger is placed parallel with the muscle fibers, but directly on the muscle. Here too, the act of swallowing greatly simplifies localization of the muscle. The actual palpating motion is made toward the median plane.



240 Palpation of the posterior belly of the digastric muscle
In many ways palpation can be performed better and more easily with the little finger. The positioning is the same as that described in Figure 239. The muscle is palpated by moving the finger from the distal toward the ascending ramus of the mandible. This differs from palpation of the stylomandibular ligament in that the palpating force is exerted deeply and not against the posterior border of the ascending ramus.

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Areas of Pain Referred from the Muscles of Mastication

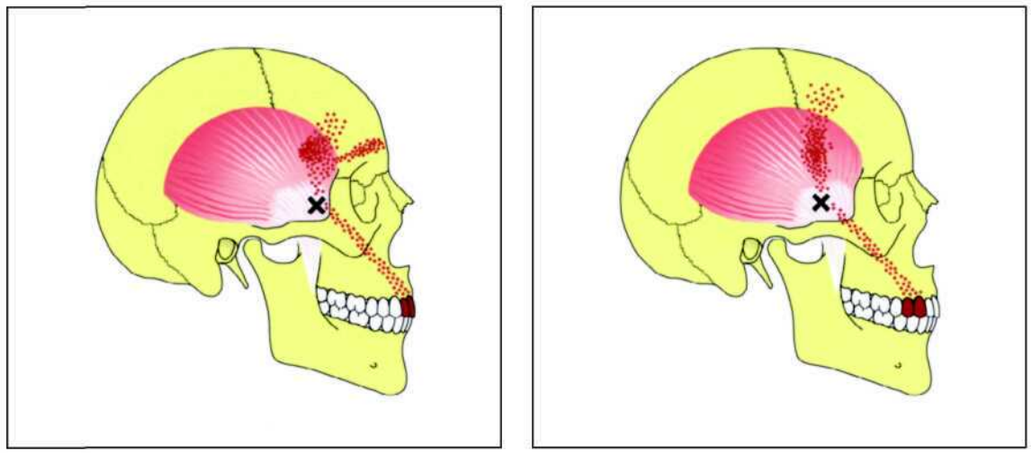
During palpation of the muscles of mastication pains can also be triggered outside the anatomical boundaries of the muscle being examined. These are called *referred pains* (Friedman et al. 1983, Travell and Simons 1983, Sessle et al. 1986). Presumably these are associated with afferent synapses in the trigeminal ganglion or in the caudal nucleus (Kojima 1990, Hong and Simons 1998). Sometimes they can mimic a pulpitis (Reeh and el Deeb 1991). For this reason patients seen in the pain clinic with chronic facial pain have often had multiple teeth extracted with no improvement of their pain symptoms. Three muscles refer pain to the teeth:

- the *temporal muscle* refers only to the maxillary teeth,
- the *masseter muscle* only to the upper and lower posterior teeth, and
- the *anterior belly of the digastric muscle* only to the lower anterior teeth.

Forty-eight percent of experimentally induced muscle pains result in referred pain. The appearance of referred pain is correlated with the intensity of the existing muscle pain (Jensen and Norup 1992).

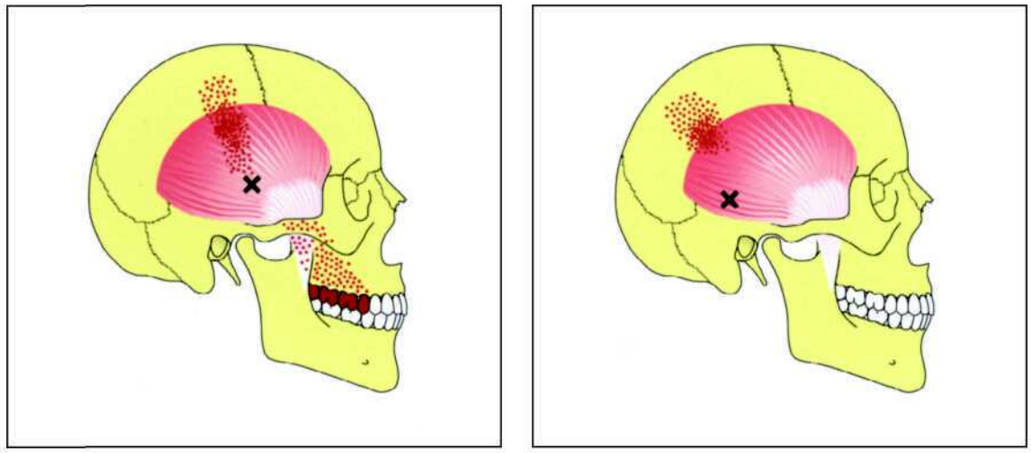
241 Myofascial pain referred from the pars anterior of the temporal muscle
Left: Areas of muscle damage (trigger points) in the pars anterior of the temporal muscle can not only cause local pain, but can also refer pain to the maxillary incisors.

Right: Other parts of the pars anterior refer pain to the canines and premolars. These pains, however, cannot be elicited locally in the teeth by application of cold, heat, or percussion.



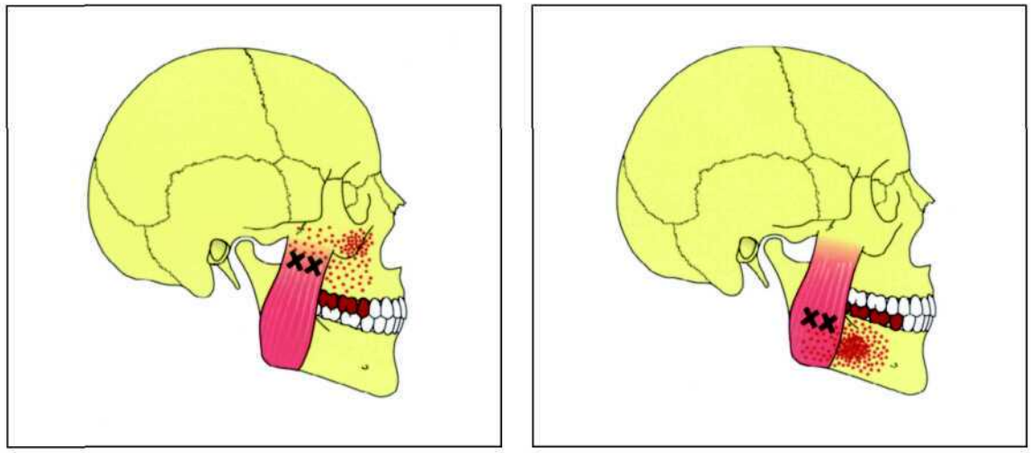
242 Myofascial pain referred from the pars media and pars posterior of the temporal muscle
Left: Trigger points in the pars media project pain to the maxillary molar region. Local anesthesia of the teeth does not alter the pain, but injection of anesthetic into the active trigger area of the muscle "switches off" the pain.

Right: Myofascial pains from the pars posterior do not radiate into the teeth, but are transmitted rather to the parietal bone.



243 Myofascial pain referred from the masseter muscle
Left: Trigger points in the superior portion of the pars superficialis of the masseter refer pain to the maxillary posterior teeth and to the maxillary sinus region.

Right: Myofascial pains originating from the inferior portion of the pars superficialis may be reported in the patient history and perceived during the isometric and palpation tests as coming from the mandibular molar region and the body of the mandible.



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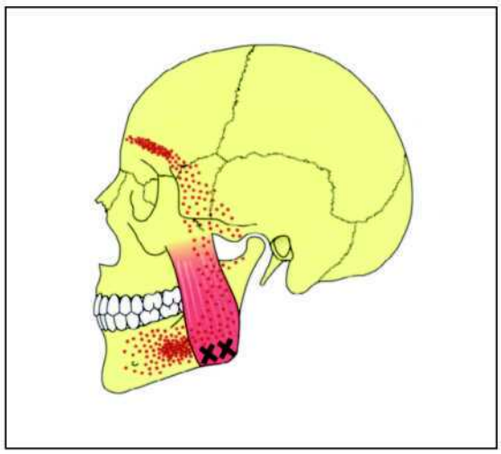
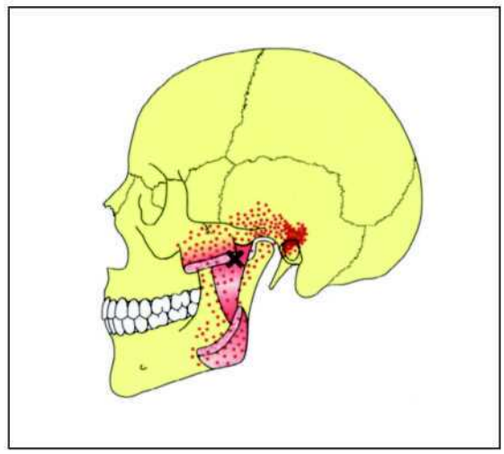
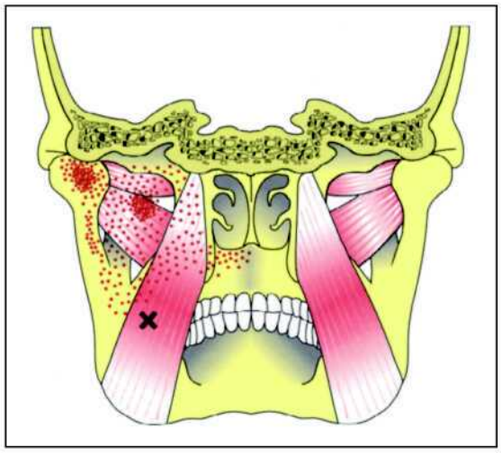


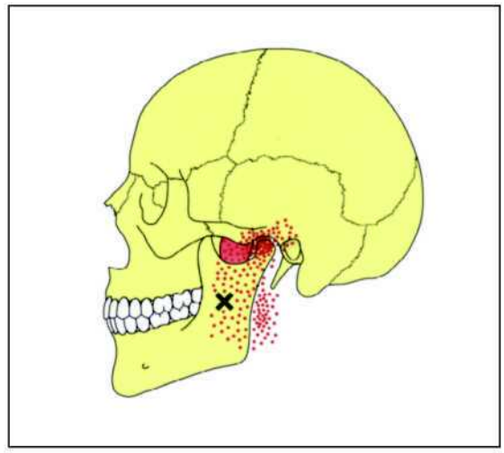


244 Myofascial pain referred from the masseter muscle

Left: The portion of the pars superficialis inserting directly onto the angle of the mandible can cause pain to be projected into the body of the mandible or into the temporal region, but not into specific dental regions.

Right: Likewise, pain is not referred from the pars profunda to the teeth. Pain from trigger points in this muscle have a greater tendency to radiate to the ear and the preauricular region.

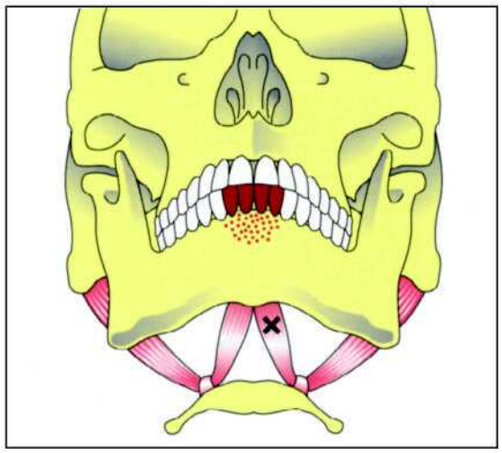


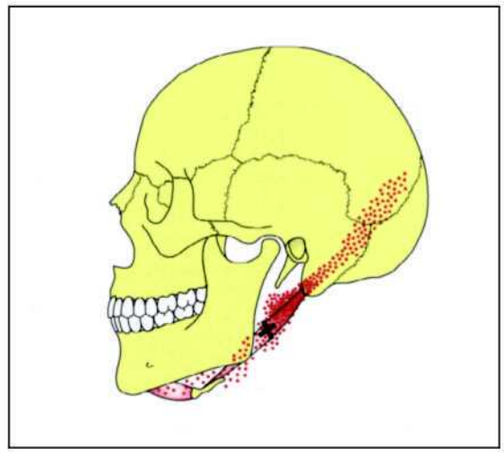


245 Myofascial pain referred from the medial pterygoid muscle

Left: Myofascial pains that originate in the medial pterygoid muscle can cause pain to be referred to the preauricular region during isometric contraction of the elevator muscles. Only the inferior end of this muscle can be palpated. Therefore, pains referred from this muscle can only rarely be provoked by palpation.

Right; Sagittal view of the region of pain referred from the medial pterygoid muscle.

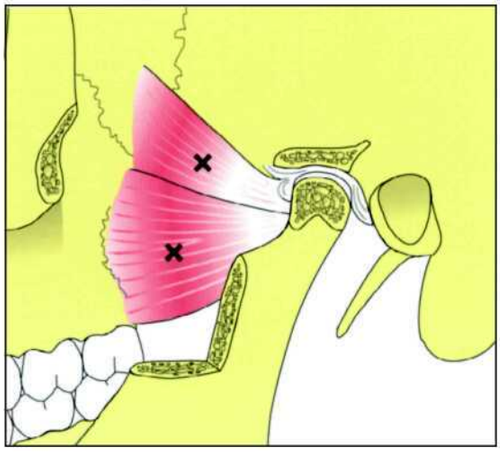


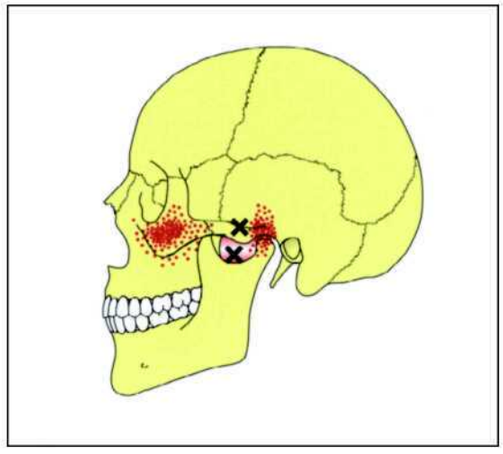


246 Myofascial pain referred from the digastric muscle

Left: Myofascial pain in the anterior belly of the digastric muscle often causes referred pain in the lower incisors. This pseudodental pain cannot be elicited by application of cold, heat, or percussion to the teeth, whereas palpation of the anterior belly of the digastric muscle does intensify the pain.

Right: Lesions in the posterior belly can cause pain that is either localized or that radiates into the mastoid region.





247 Myofascial pain referred from the lateral pterygoid muscle

Left: Because the lateral pterygoid muscle cannot be adequately palpated, local or referred pains can be provoked only by isometric contraction of the corresponding muscle.

Right: Because the muscle pain can radiate to the temporomandibuiar joint, it may be confused with an arthrogenous problem. A reliable differentiation can be made, however, with the aid of passive compressions.

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Length of the Suprahyoid Structures

The length of the suprahyoid structures depends, among other things, upon head posture (Winnberg et al. 1988). Their shortening tends to restrict the growth of the mandible (Davis et al. 1981). Stretching of the suprahyoid structures during surgical anterior repositioning of the mandible is the primary cause of skeletal relapse (Ellis and Carlson 1983). Relapse occurs after 13-27% of all mandibular advancement operations (Reynolds et al. 1988, Carlson et al. 1989). Therefore any attempt to reposition the mandible or the condyles anteriorly should be preceded by a test of the length of the suprahyoid musculature. The greater the anticipated repositioning, the more important this test is. Thus there are three chief indications for this clinical test:

- Surgical advancement of the mandible in cases of skeletal Angle Class II malocclusion.
- Orthodontic advancement of the mandible.
- Anterior repositioning of the mandible with an occlusal splint for dental restorative purposes.

Adaptation following stretching of the muscles in the suprahyoid complex takes place at the insertions and not within the muscle fibers (Carlson et al. 1987).

248 Starting position for evaluating the length of the suprahyoid structures
The patient sits upright on the treatment chair and looks straight ahead. The examiner supports the patient's neck with one hand.

249 Mandible in the end-to-end bite position
Regardless of the extent of the patient's anterior horizontal overlap (overlap), the patient should be able to assume an end-to-end bite by actively protruding the mandible.
If the treatment plan calls for correction of an extreme overjet through surgical repositioning of the maxilla and orthodontic treatment, the patient need protrude the mandible only far enough to reduce the overjet to the same measurement as the planned distal repositioning of the maxilla.

250 Position of the incisors with maximum neck extension
Before this test is carried out one must make certain that there is no history of problems in the cervical spine.
The head is tilted backward as far as possible as it is guided, but not forced, by the examiner's hand. A maximum extension of approximately 90° is possible in young patients. The patient should be able to maintain the edge-to-edge incisal relationship without significant straining. The reappearance of an overjet or an open bite during this exercise is evidence of shortening of the suprahyoid musculature.

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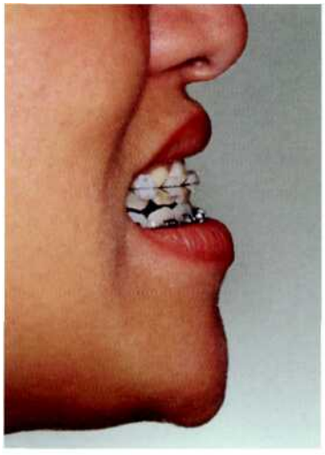
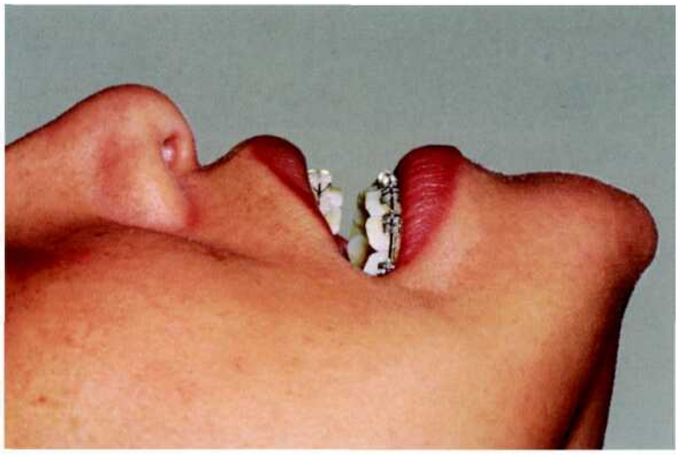
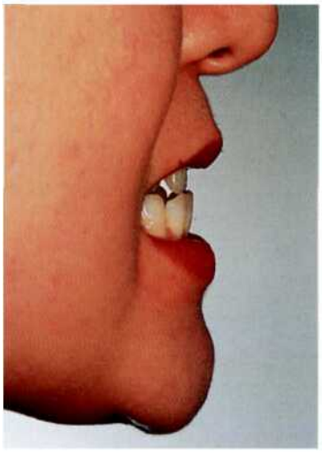
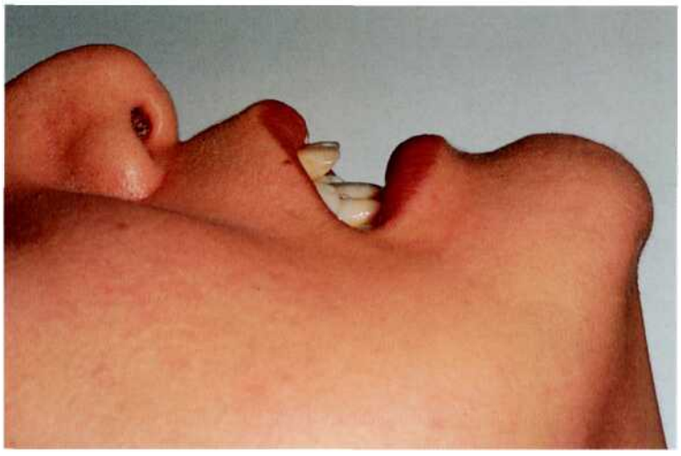




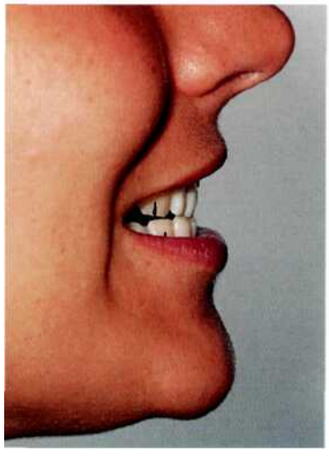
251 Vertical shortening of the suprahyoid structures
Left To measure a vertical shortening of the suprahyoid muscles the patient, sitting upright, places the incisors in edge-to-edge contact without regard to how much horizontal overlap is present in centric occlusion. If the incisors separate during extension of the neck, the distance between the incisal edges is measured in millimeters and recorded in the chart as "vertical shortening." This distance is only a relative quantity and does not represent the actual shortening of the muscles.

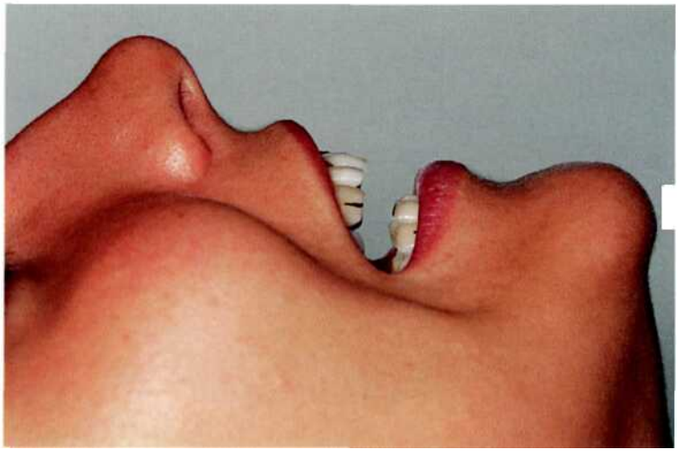




252 Horizontal shortening of the suprahyoid structures
Left: To measure horizontal muscle shortening the patient again moves the mandible forward into an anterior edge-to-edge position. Obviously this is not possible if the patient has a reverse horizontal overlap (prognathic occlusion), but in these cases the length of the suprahyoid muscles is of no therapeutic significance.

Right: Horizontally shortened muscles cause a horizontal overlap to reappear when the neck is extended. A measurement of this overjet is recorded on the examination form.





253 Combined shortening of the suprahyoid structures
If, during the extension movement, the incisal edges of the lower incisors are displaced both posteriorly and inferiorly, this is referred to as a combined shortening of the suprahyoid structures. In these cases the amount of vertical opening and the renewed horizontal anterior overlap are determined and entered in the examination record. Shortening of the suprahyoid musculature should be eliminated during the course of orthodontic treatment of a skeletal Angle Class II malocclusion.

Length of the suprahyoid structures

Vertical shortening	mm
Sagittal shortening	mm

Positive palpation findings

Right	Left

254 Excerpt from the examination form
The relative magnitude of the shortening of the suprahyoid structures is entered on the examination form in millimeters. The shortening may occur in only one direction or in a combination of both directions. Evaluation of the length of the suprahyoid structures is necessary only when anterior repositioning of the mandible is contemplated as part of a prosthodontic or orthodontic treatment. The box labeled "Positive palpation findings" is associated with isometric contractions.

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Investigation of Clicking Sounds

Joint sounds can be divided into rubbing sounds and clicking sounds. The former have already been discussed at the beginning of this chapter. There is controversy in the literature concerning both the diagnostic and therapeutic aspects of clicking phenomena. The reported *incidence* of joint sounds varies from 34% to 79% (Agerberg and Carlsson 1975, Rieder et al. 1983, Gay and Bertolami 1988, Wabeke et al. 1989, Pöllmann 1993) depending on the selected patient population and the manner of gathering information (questionnaire, palpation, stethoscope). Basically this means that more joint sounds can be detected clinically than are reported by patients (Sadowsky et al. 1985, Hardison and Okeson 1990). Temporomandibular joint sounds are already exhibited in 7.8% of 3-7-year old children (Alamoudi et al. 1998). Between the ages of 7 and 20 years the incidence of sounds increases by approximately 20% (Egermark-Eriksson et al. 1981, Nilner 1985, Magnusson et al. 1985, Könönen et al 1996). The majority (53%)of these are found to be reciprocal clicks with the initial click during jaw opening and a terminal click during closing (Muhl et al. 1987, Wabeke et al. 1989). Twenty-two percent are closing clicks only, 13% are opening clicks only, and 12% are multiple sounds.

255 Examination form
At the beginning of the 1990sa new concept for the differential diagnosis of clicking sounds in the temporomandibular joint was developed based upon the knowledge gained over the previous decades. The main parameters upon which this concept is based are the intensity and timing of the sounds and their changes during manipulation. The findings are always compared with non-manipulated active movements. Studies of the reliability of these methods show a high level of specificity and sensitivity (Bumann and Zaboulas 1996).

Dynamic compression and Translation (clicking sounds)

Active movement		Dyn. compression, excursive		Dynamic translation										Dyn. compression, incursive	
Right	Left			Group I				Group II				Group III			
		R	L	Lat+compr.		Med+compr.		Lateral		Medial		Lateral		Medial		R	L
Timing of sound				R	L	R	L	R	L	R	L	R	L	R	L		
Intensity of sound																	

Ø no sound + louder/later 0 the same – quieter/earlier

The most common causes (70-78%) of clicking sounds in the temporomandibular joint are *disk displacements* of various degrees and in various directions, but predominantly anteromedial (Dawson 1989, Bumann and Groot Landeweer 1993, Tasaki et al. 1996). In the physiological state the pars posterior of the disk is in the fossa and the pars intermedia lies between the condyle and the articular protuberance (Lubosch 1906). Stability of the disk on the condyle is provided by the superior and inferior strata of the bilaminar zone and the convexity of the disk's pars posterior (Osborn 1985, Isberg and Isacsson 1986, Stegenga 1991, Eriksson et al. 1992, Müller-Leisse et al. 1997). The inferior stratum must become overstretched before anterior disk displacement can occur.

In making a diagnosis it is important to differentiate between a partial and a total disk displacement (Bumann and Groot Landeweer 1993, Tasaki et al 1996, Rammelsberg et al. 1997). The extent of displacement can remain constant for many years (Farrar and McCarty 1979, Könönen et al 1996). However, 9% of disk displacements *with* repositioning (reducing disk displacements) can degenerate into disk displacements without repositioning within 3 years (Lundh et al. 1987). In addition to displacements, adhesions can also occur. They have often been described in the upper joint space (Montgomery et al. 1989, Kryshtalskyj and Weinberg 1996, Sandier et al. 1998) but are seldom found in the lower joint space (Bewyer 1989, Kahnberg et al. 1997). Axiographic tracings do not provide adequate information to be used for the differential diagnosis of clicking sounds (Rammelsberg et al. 1997, Bumann and Groot Landeweer 1991, Parlett et al. 1993, Fushima 1994, Lund et al. 1995, Ozawa and Tanne 1997).

Besides disk displacement, there are a number of other causes of clicking sounds in the temporomandibular joint (Remington et al. 1990, Bumann and Groot Landeweer 1992, Prinz 1998). For example, 22-25% of patients with clicking sounds show a normal disk position in MRI (Davant et al. 1993, Müller-Leisse et al. 1996). Contrary findings have also been reported: 15% of a group of subjects with no clinical symptoms show some form of disk displacement on an arthrogram (Westesson et al. 1989). Of the asymptomatic subjects, 32-35% showed an anterior disk displacement in the MRI (Kircos et al. 1987, Davant et al. 1993, Katzberg et al. 1996, Tallents et al. 1996, Tasaki et al. 1996). The explanation is that these subjects had either

- a tendency toward disk displacement (see p. 78, Fig. 187) or
- a perfect adaptation of the bilaminar zone (see p. 170) with formation of a pseudodisk (Blaustein and Scapino 1986).

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In summary: Clicking sounds in the temporomandibular joint are either caused by different forms of anterior disk displacement or are not associated with the disk. The cause may be:

- disk hypermobility
- partial disk displacement
- total disk displacement
- disk displacement with disk adhesion
- disk displacement with terminal repositioning
- lateral ligament impingement (Pinkert 1979)
- hypertrophic cartilage (Hansson and Öberg 1977)
- condyle hypermobility (Oster et al. 1984).

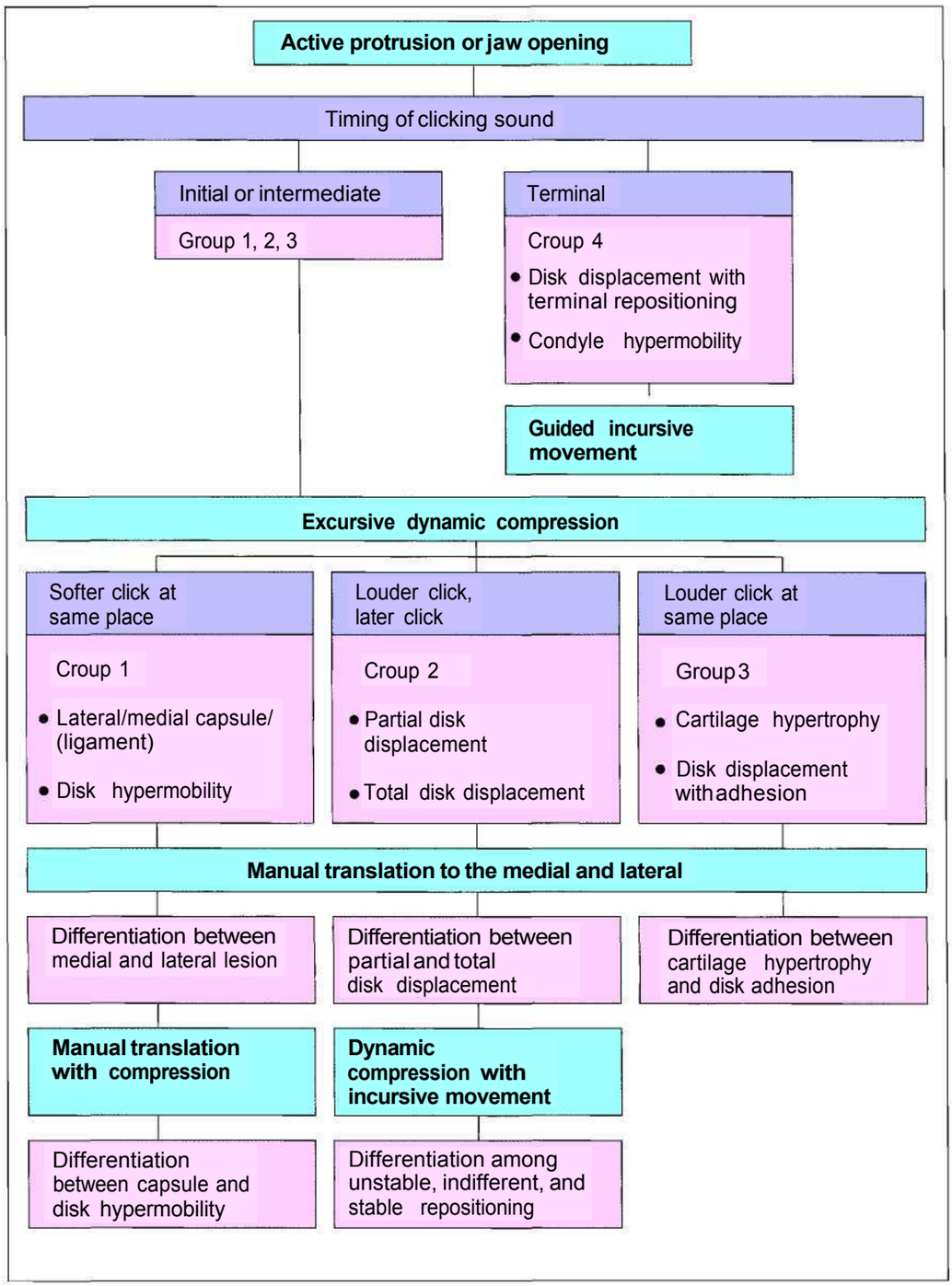
The following classification simplifies the differential diagnosis:

Group 1
- Lateral and/or medial ligaments
- Disk hypermobility

Group 2
- Partial or total disk displacement

Group 3
- Disk displacement with adhesion
- Hypertrophic cartilage

Group 4
- Condyle hypermobility
- Disk displacement with terminal repositioning



256 Examination techniques and findings for the differentiation of joint sounds

There are three chief indications for differentiation of clicking sounds in the temporomandibular joints:

- Examination prior to dental restorative or orthodontic treatment to document the *initial conditions.*
- Diagnostic procedures for determining the cause of the clicking sound.
- Diagnostic procedures for determining the *extent of a disk displacement* so that the prognosis of any contemplated treatment can be estimated.

A basic prerequisite for clinical differentiation of clicking sounds is the presence of sounds that are clearly audible to both patient and examiner. If the sounds cannot be repeatedly and predictably detected during active movements, or if the examination parameters of timing and *intensity* of the sound cannot be definitely modified through manipulation, then the sounds can provide no answers to the questions concerned with treatment.

The clinician can benefit from the following rule: *If clicking sounds cannot be unequivocably diagnosed or repeatedly provoked, they cannot be treated with the expectation of long-term* success. The converse conclusion that every diagnosable clicking sound must be treated is not true, however.

The protocol outlined here is made up essentially of the investigation of active movements, manual excursive compressions, manual incursive translations, and manual incursive compressions. The individual techniques are described on the following pages.

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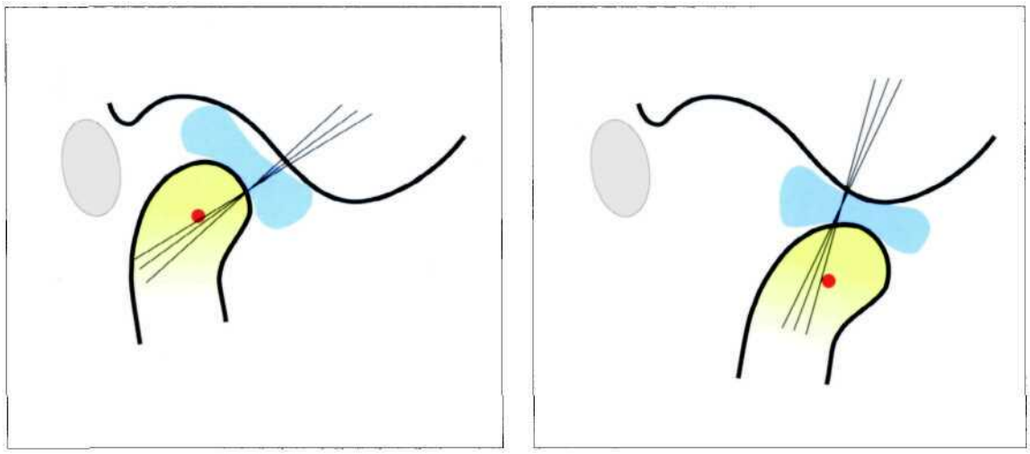
257 Clicking from the lateral wall of the joint capsule

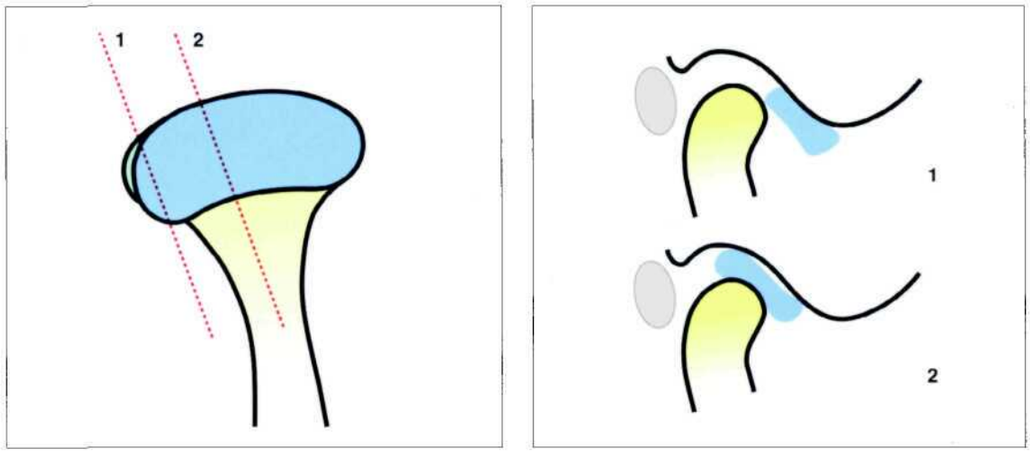
When the jaws are closed *(left)* the lateral pole of the condyle (red) lies behind the lateral ligament. During jaw opening (right) the pole crosses under the ligament. Normally this causes no noise. Sound is produced only with increased tension (activity of the suprahyoid muscles, balancing contacts or nonworking interferences) or an enlargement of the lateral pole of the condyle. The latter phenomenon occurs in 12% of all joints (Griffin 1977) and is responsible for approximately 8% of all clicking sounds.



258 Disk hypermobility

Left With the jaws closed the lateral part of the disk is displaced slightly forward. Disk hypermobility is a very early stage of a disk displacement, corresponding to stage 1-2 according to Dawson (1989). Occasionally disk displacement can begin medially instead of laterally.

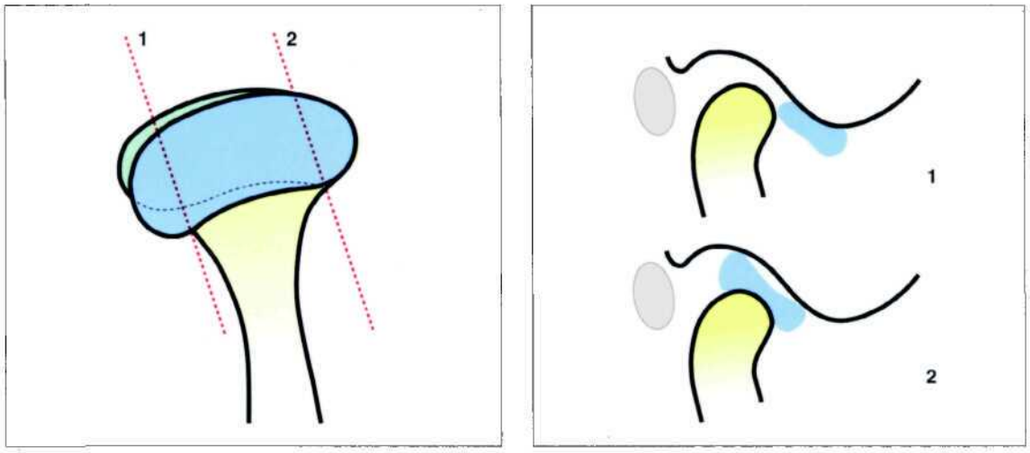
Right: The position of the disk appears differently in a sagittal section through the lateral portion of the joint (1) than it does in a section through the central portion (2). In the lateral section the disk is displaced anteriorly but in the central section its position is physiological.



259 Partial anterior disk displacement

Left: As far as the pathology is concerned, a partial disk displacement is an advanced form of disk hypermobility. In this condition a larger portion of the disk is anteriorly displaced. In the medial portion, however, the disk still lies over the condyle.

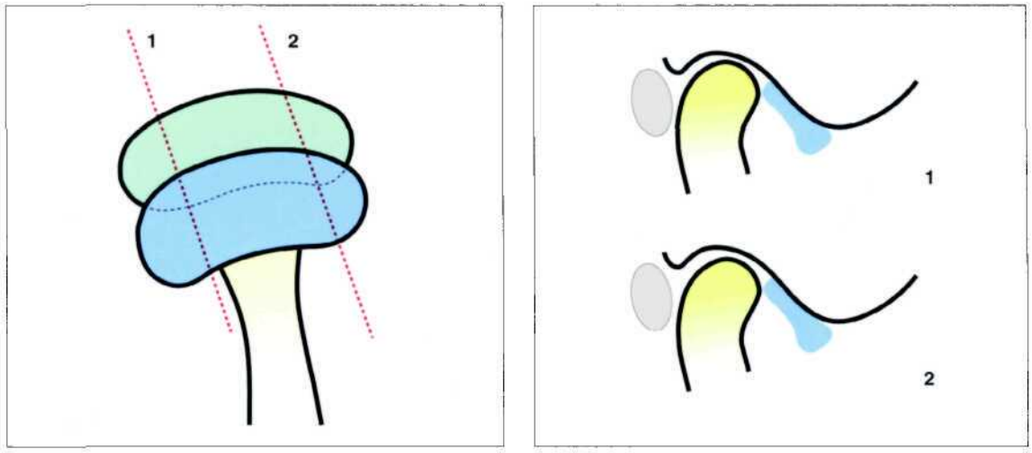
Right: This sagittal view shows an anteriorly displaced disk in the lateral section (1) and a normal disk position in the medial section (2). In the central section there is frequently a tendency toward displacement.



260 Total anterior disk displacement

Left: Both the lateral and medial portions of the disk are anteriorly displaced. The inferior stratum of the bilaminar zone is thereby overstretched across its entire breadth—an unfavorable structural condition for treatment because an important stabilizing factor is lacking.

Right: In sagittal views, identical disk-condyle relationships are seen in both the lateral (1) and medial (2) sections.



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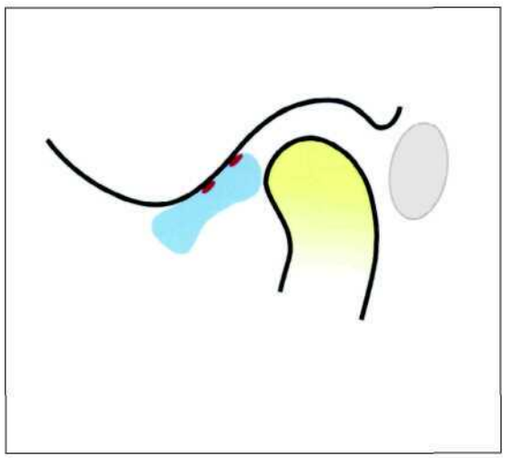
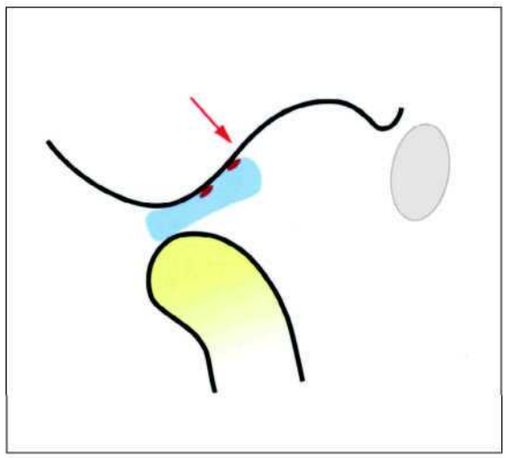
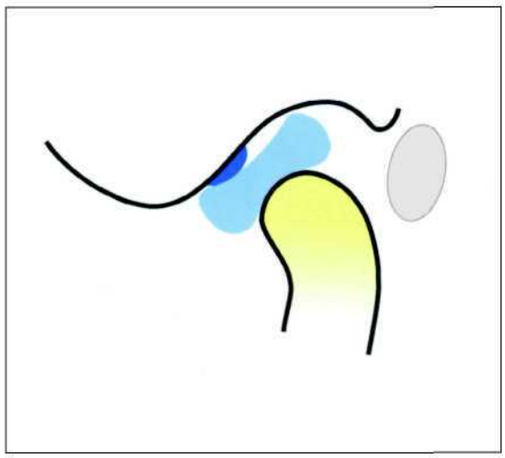


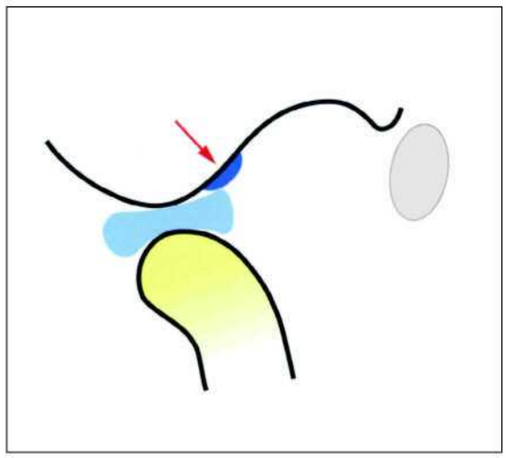


261 Disk adhesion with anterior disk displacement
Clicking sounds in combination with disk adhesions can be diagnosed clinically only if the disk adhesions are associated with disk displacement. In this case translation of the displaced disk relative to the temporal bone is restricted. Approximately 10% of all clicking phenomena are the result of disk displacement with disk adhesion.

Left: Jaws closed.

Right: The clicking occurs at the same place (arrow) during both opening and closing.

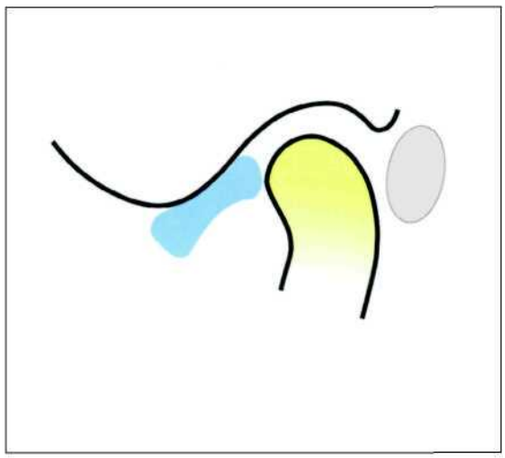


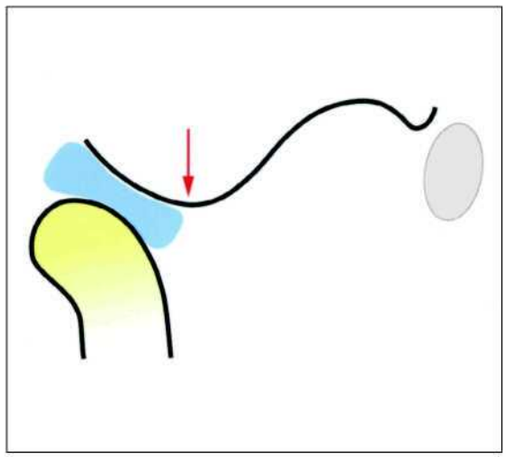


262 Cartilage hypertrophy (deviation in form)
Changes in the joint surfaces can likewise be the cause of clicking sounds in the temporomandibular joint (Hansson et al. 1977). Even though the incidence of cartilaginous changes is quite high in studies on cadavers, this phenomenon is reproducibly diagnosed only rarely in MRI screening of clinical patients.

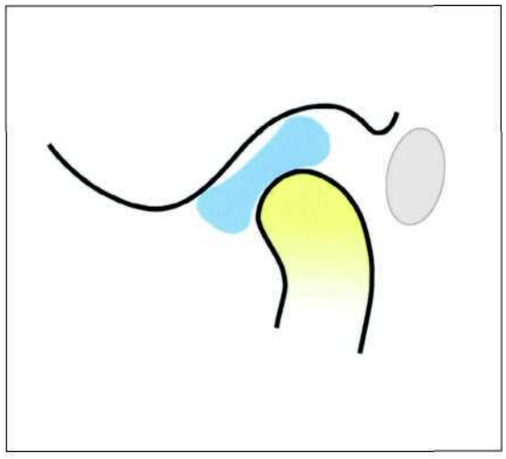
Left: Jaws closed.

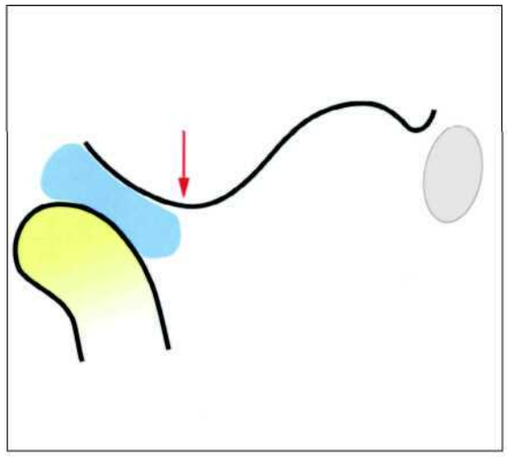
Right The clicking always occurs at the same point (arrow) along the path of movement during opening and closing.





263 Anterior disk displacement with terminal repositioning
This phenomenon is not a unique functional disturbance, differing only in the time at which repositioning occurs from the causes of clicking discussed in Figures 259 and 260 (initial to intermediate repositioning). While the jaws are closed *(left)* the disk is anteriorly displaced. Not until the end (terminal stage) of the jaw opening movement *(right)* does it become repositioned over the condyle with a click. This phenomenon is frequently associated with hypermobility of the condyle.





264 Anterior hypermobility of the condyle
Here there is over-rotation of the disk-condyle complex beyond the crest of the articular eminence. During this over-rotation, which is a relatively common occurrence, distinct clicking sounds will not arise unless the joint surfaces are rounded and the coefficient of friction is elevated by an altered composition of the synovial fluid. Clicking occurs in approximately 10% of all patients with condyle hypermobility.

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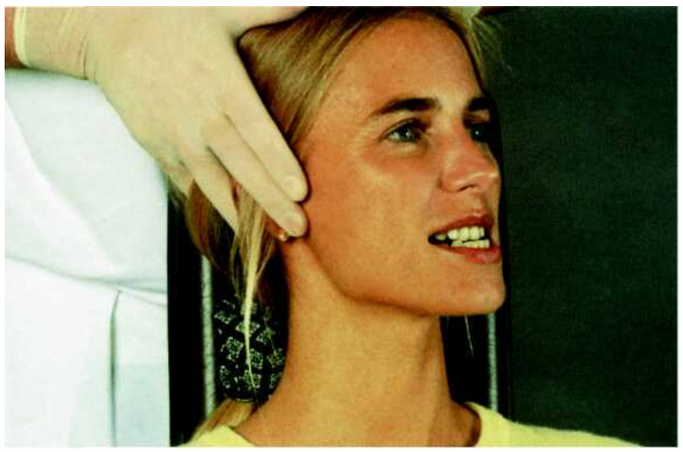
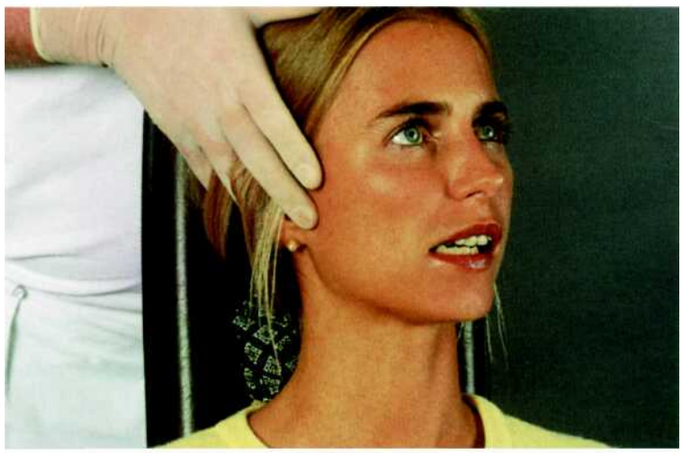
Active Movements and Dynamic Compression

At the beginning of the examination the clicking sounds that occur during active movements are recorded. These will serve as a reference for all subsequent tests. Only those clicking sounds that can be repeatedly detected are differentiated. All other sounds are merely documented in the patient's records. Detection of the sounds though palpation is very dependable (Westling et al. 1992, de Wijer 1995). Palpation with a finger in the external auditory canal (Friedman 1988) is to be avoided because this can cause iatrogenic sounds (Hardison and Okeson 1990). Use of expensive instruments is not necessary (Wabeke et al. 1994). However, the SonoPak System (Bioresearch, USA) can be used to advantage for excluding or documenting pretreatment sounds (Ishigaki et al. 1993, Bumann et al. 1999). The timing *of the click* is classified as either initial, intermediate, or terminal (Farrar 1978). Dynamic compressions are added (Fig. 299ff) to complete this part of the examination. This technique produces reliable diagnostic information (Widmer 1988, Bumann and Zaboulas 1996, Yatani et al. 1998).

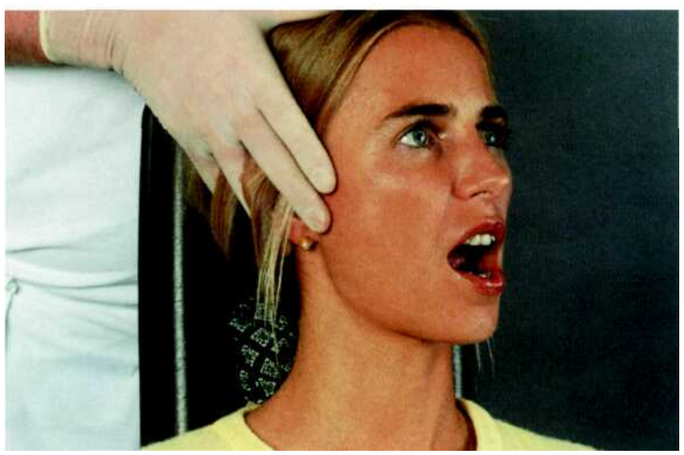
265 Active protrusive movement
To detect a reproducible clicking sound during protrusive movements the fingers are placed with minimal pressure over the poles of the condyles. The patient then executes a maximal active protrusive movement. The examiner notes the timing of the click (initial, intermediate, or terminal) and the distance of the movement. Unlike other movements, protrusion allows the timing of the click to be quite reliably determined, even by the inexperienced examiner.



266 Active mediotrusive movement
Clicking sounds associated with active jaw movements can also be detected during mediotrusion. Although it is not usually necessary, it is always helpful to have the patient report the sounds during this movement. It is also a good idea to take note of any bilateral clicking during the mediotrusive movement so that the two phenomena can be investigated independently.



267 Active jaw opening
Testing during active jaw opening is the most frequently used method for detecting clicking sounds. If the sounds can be clearly detected at this time, the other movements are not tested. Accordingly, examination for joint sounds always begins with active opening. After the fingers are in position, the patient opens the mouth as far as possible. During this phase it is only the timing and intensity of the click that are of interest, as these will be used as references for the succeeding movements.



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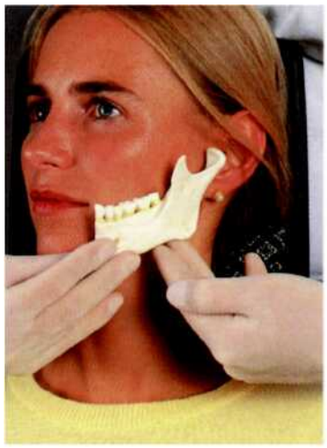
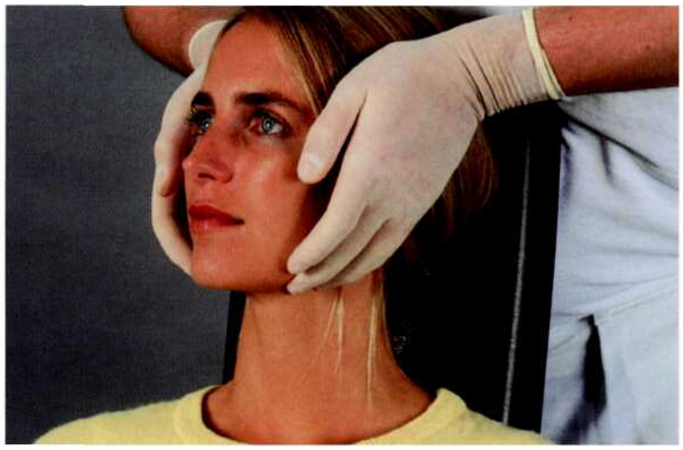
Active movement		Excursive dynamic compression	
Right	Left		
Initial	Intermediate	R	L
Timing of sound			
Intensity of sound			

268 Examination form
Timing of the clicking sounds during active movements is recorded in the appropriate section of the examination form (see p. 57) as follows:
- If the joint clicks just as the movement begins, an entry of "initial" is made.
- If the click occurs at the end of the movement it is recorded as "terminal."
- All other sounds are designated as "intermediate."

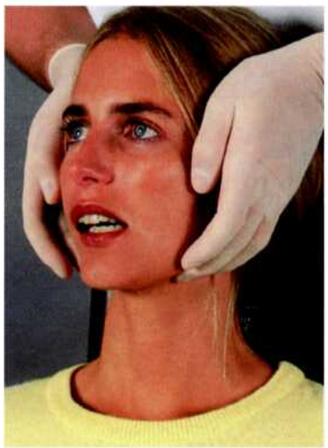
Recorded here are an initial click in the right joint and an intermediate click in the left.

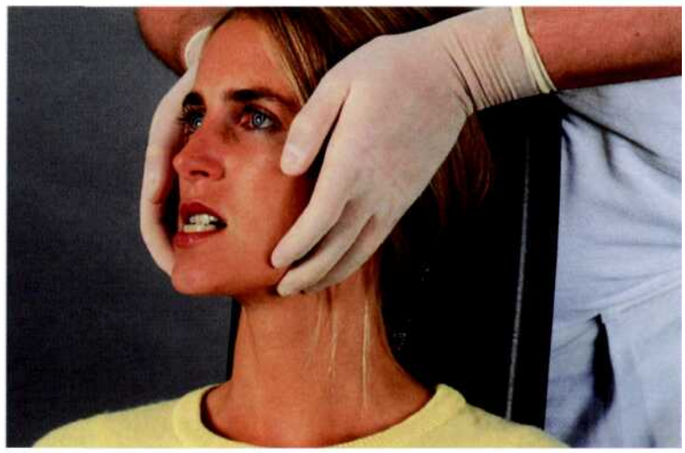




269 Technique for dynamic compression
To apply superior compression, either the index and middle fingers or the middle and ring fingers are placed under the angles of the jaw so as to cause the least amount of discomfort.

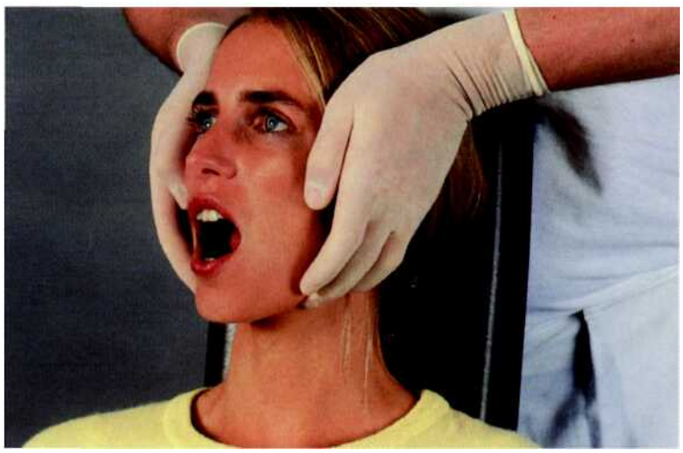
Left: The manipulation technique for differentiating clicking sounds is the same as the technique used previously for testing the joint surfaces. If the joint surface tests were painful, accurate diagnostic tests for joint sounds cannot be carried out.





270 Dynamic compression
A compressed protrusive movement carries with it the advantage of a reproducible determination of the timing of the sound. Unfortunately, the clicking sounds do not always occur during protrusion.

Left Depending upon which active movement produced the clicking sounds to be recorded, a dynamic compression test is now carried out for mediotrusion, protrusion, or jaw opening. Bilateral sounds can be easily separated by means of the compressed mediolateral movement.



271 Dynamic compression during jaw-opening movement
If clicking sounds were detected during active jaw opening, a dynamic compression test for jaw opening is now performed. Both the patient and examiner remain alert to any changes brought about in the *intensity* of the sound compared with that of the active movement. The sound may now be louder, softer, or of the same intensify. In addition, the examiner notes the *timing* of the sound (at the same point or later). This is not determined by the interincisal distance (see pp. 108f)!

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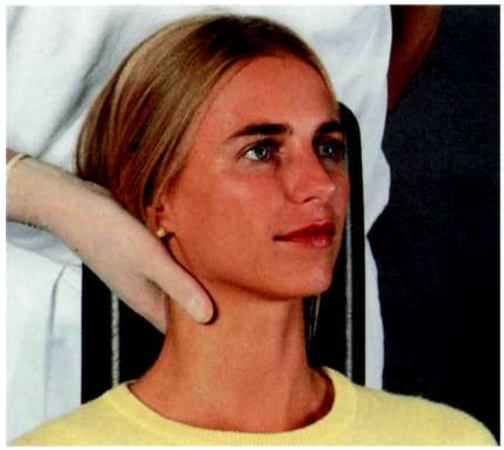
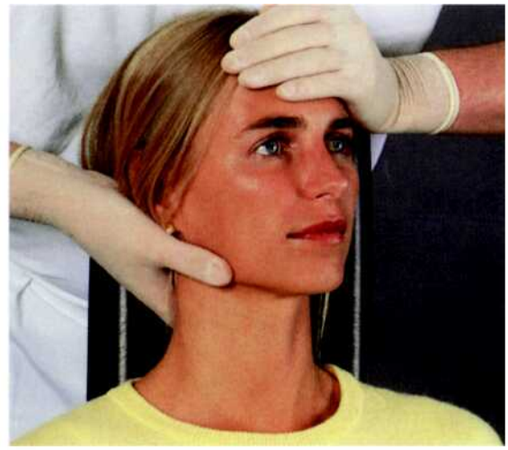
Manual Translations

The next step in differentiating clicking sounds in the temporomandibular joint is the evaluation of active movement sounds in regard to the parameters of timing and intensity of the clicks (Fig. 256). If the timing of the clicking sound is initial or intermediate, a group 1, 2, or 3 situation is present, If there is a terminal click during excursive movements, this indicates the presence of a group 4 phenomenon. By applying the *dynamic compression* described previously, the parameters of timing and intensity can be specifically altered. In this way, distinctions among groups 1, 2, and 3 can be made (p. 108ff). After the correct group diagnosis has been made on a particular patient through movements under dynamic compression, the next step in the examination is *differentiation among the groups* through *manual translations.* These are divided into lateral and medial manual translations. For group 1 phenomena the translations are combined with superior compression. For simplification the translation tests are arranged by the specific groups in the examination form (Fig. 275).

272 Positioning the hands for manual translation to the left
Left: For manual translation to the left the right hand is placed against the back of the patient's neck.

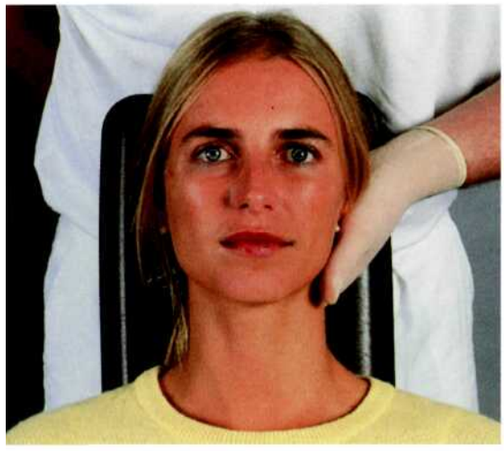
Right: The left hand supports the patient's forehead from the opposite side. Next the clinician exerts a medial pressure against the right angle of the jaw with the right thumb. This results in a medial translation of the right condyle and a lateral translation of the left.

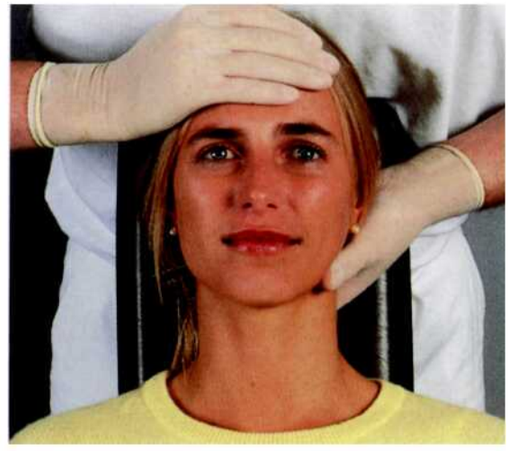




273 Positioning the hands for manual translation to the right
Left: This frontal view shows the procedure repeated for the opposite side. Now the left hand is stabilizing the patient's neck.

Right The right hand supports the forehead as pressure by the left thumb produces a medial translation of the left condyle and a lateral translation of the right. No mediotrusive movement should result from this technique.

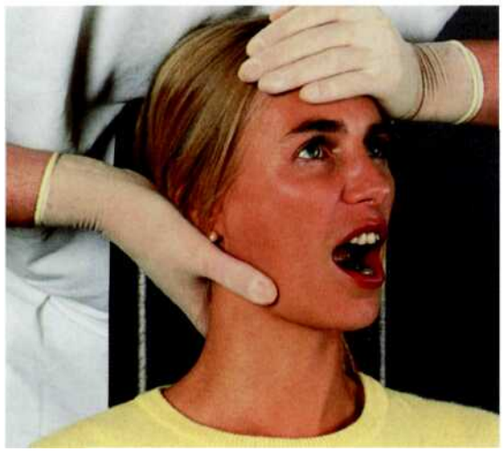


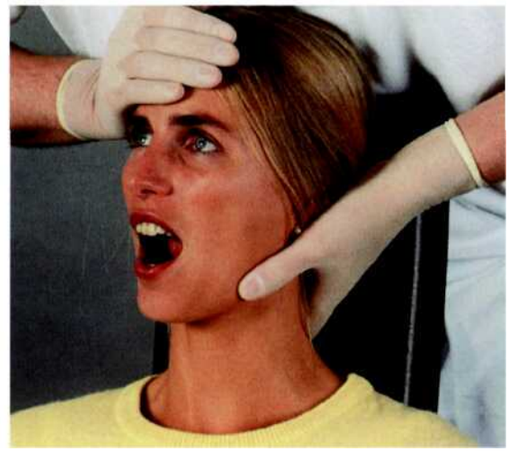


274 Maximal jaw opening during manual translation
These tests are used for groups 2 and 3.

Left: The patient opens the mouth as far as possible under constant exertion of the translating pressure. Both clinician and patient monitor the intensity of the clicking sound and compare it with that of active movements. The clinician ensures that the amount of movement is the same as during the active movement.

Right: An analogous procedure is carried out for the other side.





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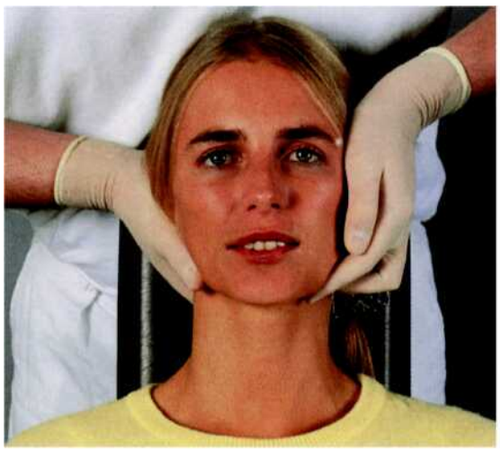
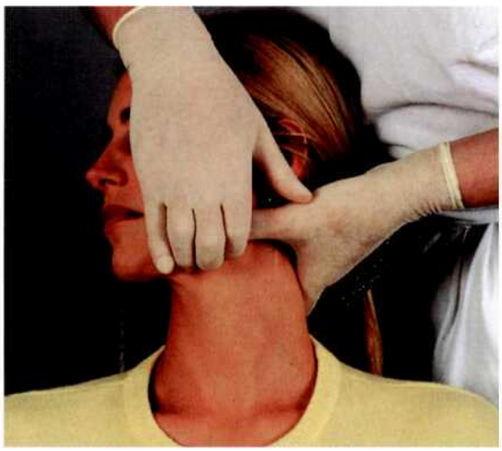
Manual translation											
Group I				Croup II				Group III			
Lat+compr.		Med + compr.		Lateral		Medial		Lateral		Medial	
R	L	R	L	R	L	R	L	R	L	R	L

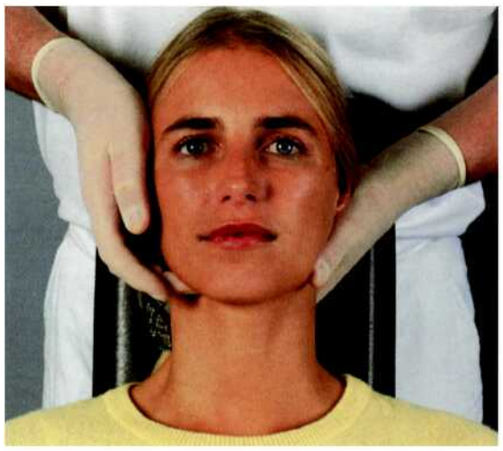
275 Examination form
Following the dynamic compressions the manual translations are performed to differentiate between the two clicking phenomena in each group. During this test the examiner and patient need only compare the intensity of the sound to that of active movement. Louder sounds are indicated in the record with "+," softer sounds with "-," and sounds of equal intensity with "0." In this way it is possible to differentiate among the total of eight clicking phenomena (see also Fig. 256).

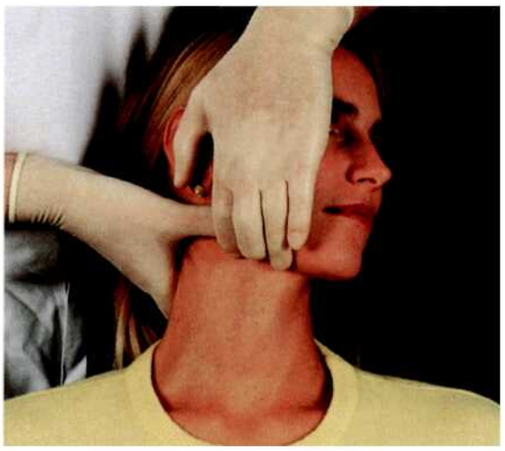




276 Positioning the hands for manual translation with compression to the left
Left: Lateral manual translation with compression for the left joint. The right hand provides the translation while the left hand adds superior compression. The side that is being tested is always the compressed side.

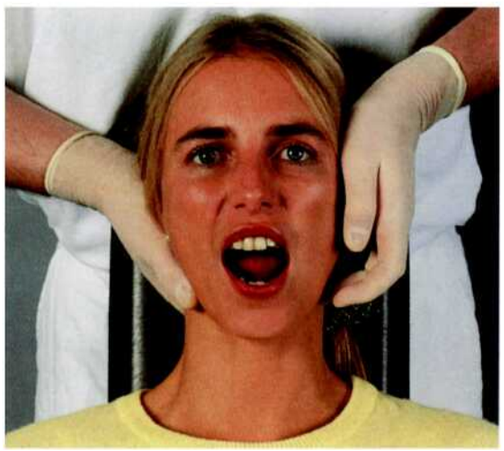
Right: Medial manual translation with compression for the left joint. The left hand produces the medial translation and the right hand produces the compression.

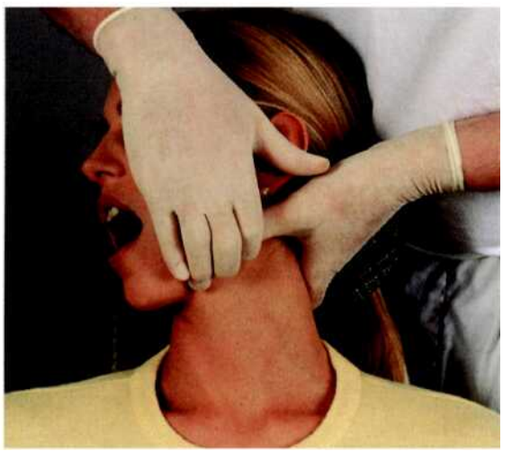




277 Positioning the hands for manual translation with compression to the right
Left: Lateral manual translation with compression for the right joint. The left hand provides the translation and the right hand adds the superior component of force. Again, the side that is being tested is the compressed side.

Right: Medial manual translation with compression for the right joint. The right hand provides the medial translation and the left hand the compression.





278 Maximal jaw opening during manual translation with compression
These tests are used specifically for differentiations within group 1.

Left: While the examiner maintains the translating and compressive forces, the patient opens her mouth as far as she can. Examiner and patient again observe and compare the intensity of the clicking sound with those of active movements and manual translations without compression.

Right: The other side is examined in an analogous manner.

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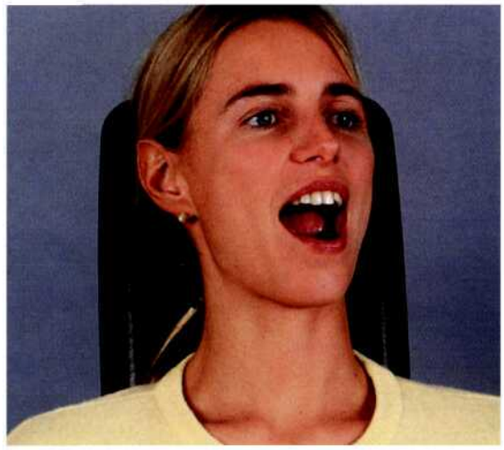
Dynamic Compression during Retrusive Movement

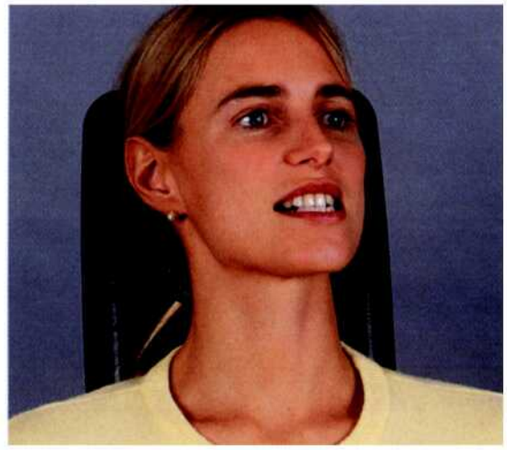
The retrusive dynamic compression test is carried out only if the preceding course of the examination points to a group 2 condition. Within this group a further distinction can be made between a partial and a total disk displacement by performing lateral and medial manual translations. These tests are quite sensitive and specific (Bumann and Zaboulas 1996).

Retrusive dynamic compression serves to test the *convexity of the pars posterior* of the disk. The rationale for this is that the convexity of the pars posterior shares the responsibility for a stable position of the disk on the condyle (Osborn 1985, Müller-Leisse et al. 1997). As long as the pars posterior has a certain degree of convexity, the disk cannot pass anteriorly through the narrow space between the condyle and the protuberance (see also pp. 108,109, and 122). A persisting convexity, therefore, is a favorable condition for the prognosis of any contemplated repositioning treatment. The essence of the test is the comparison of an active retrusive movement with a manipulated retrusive movement, both made from the maximally protruded position,

279 Active jaw opening
Left: The starting point for this test is the maximum jaw opening, at which the click occurs. The act of opening causes the disk to slip back over the condyle and at this point a normal disk-condyle relationship is reestablished.

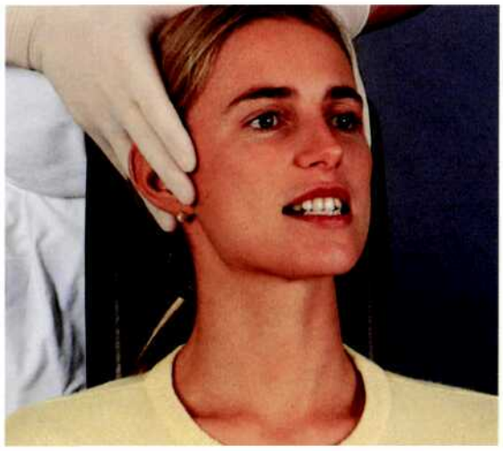
Right: Next the patient is asked to close into the maximally protruded position. In this position the disk still lies over the condyle.

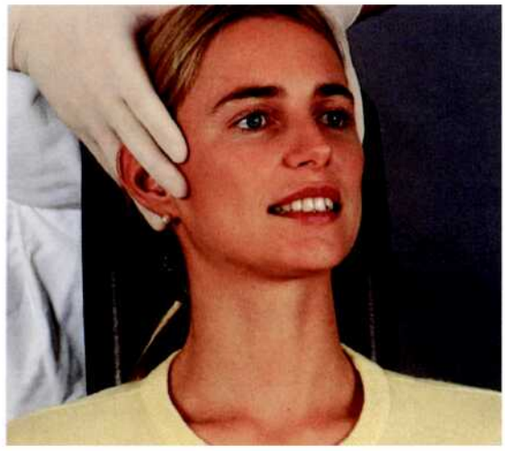




280 Active retrusive movement
Left: From the maximally protruded position the patient is instructed to slowly move the lower jaw back (active retrusive movement).

Right: By palpating the moving condyles with minimum pressure the examiner can feel the click of luxation as the disk again slips off the condyle. As a rule, this closing click occurs as a terminal click (Farrar and McCarty 1979, Cay et al. 1987). The exact point at which it occurs can be marked on the teeth.





281 Posterior movement to the click of luxation
Left: To make an accurate record of the luxation click, a distinct mark is made on a maxillary tooth before the test is conducted. Here the jaws are shown closed in the protruded position after having been opened widely.

Right: During the slow posterior movement of the mandible the examiner can not only monitor the condyles by palpation, but can also follow the retrusive movement visually and make a mark on a lower tooth at the point at which the click occurs.

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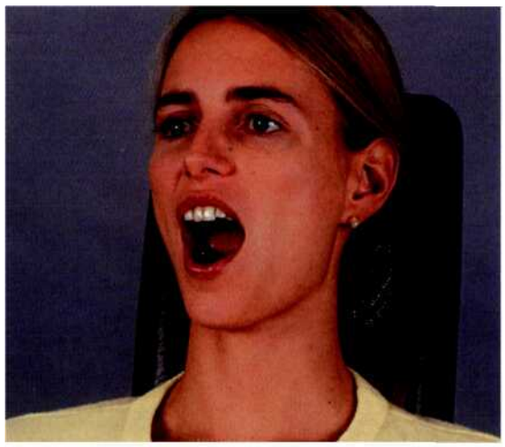
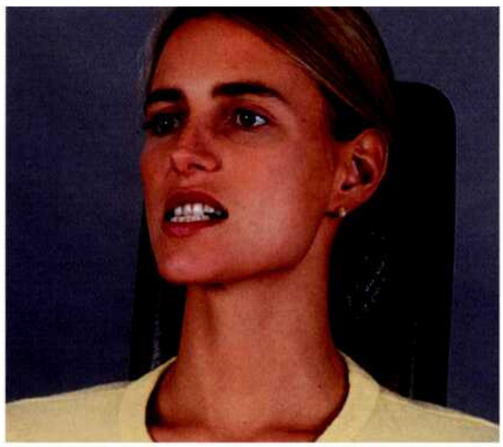
Group II			
Lateral		Medial	
R	L	R	L

Retrusive dynamic compression	
R	L

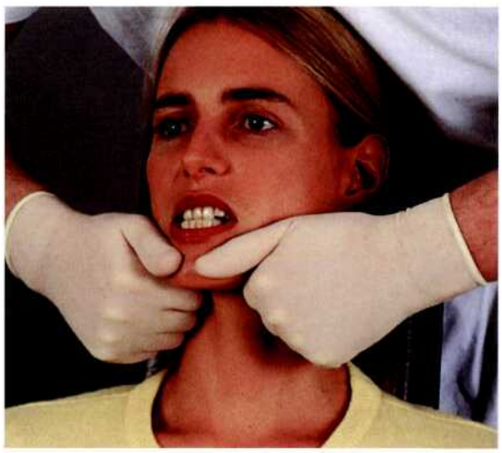
282 Examination form
The last part of the examination form for the differentiation of clicking sounds contains spaces for the retrusive dynamic compressions. These serve to test the convexity of the pars posterior of the disk. The timing of the click during a manipulated retrusive movement is compared with that of an active retrusive movement. Sounds that occur earlier are entered with "-" and those that occur later are designated by"+." If the sounds occur at the same point as during active movement, the finding is noted as "0."

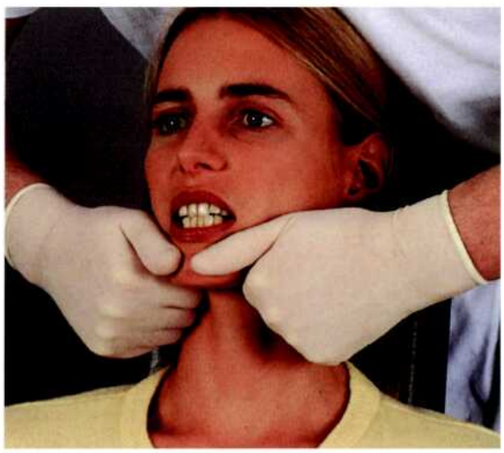




283 Repetition of jaw opening and closing in protrusion
Left: After recording the active findings as a reference, the patient again opens her jaws. This again causes the disk to be repositioned on the condyle.

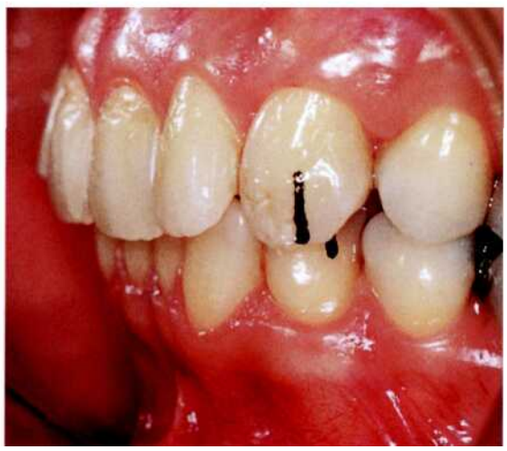
Right: From the position of maximal opening the jaw is again closed in maximal protrusion. The disk still lies atop the condyle.





284 Dynamic compression during retrusive movement
Left: Anterosuperior compression is applied with the mandible maximally protruded. The technique is similar to the "Dawson grasp" (Dawson 1989) except that the starting position is different.

Right Under sustained anterosuperior compression, the patient slowly slides the lower jaw posteriorly with the teeth touching. The point at which the click occurs is compared with that for the active movement and recorded.



285 Differentiation between stable and unstable repositioning
Left: If the click of a manipulated retrusive movement occurs earlier (the lower mark is anterior to the upper) then the pars posterior is flattened and this is described as an unstable repositioning.

Right If the click of the manipulated retrusive movement occurs later, the pars posterior is still convex and the repositioning is designated as stable. These techniques are very sensitive and specific (Bumann and Zaboulas1996).

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Differentiation among the Groups

Group 4: Clicking Sounds due to Disk Displacement with Terminal Repositioning or Condyle Hypermobility

Anterior disk displacements arise because of posterior or posterolateral loading vectors. There can be multiple causes for these loading vectors in an individual case. The amount of overstretching of the inferior stratum and the degree of flattening of the pars posterior are responsible for the amount of disk displacement. As long as there is exclusively posterior loading with no superior component, disk displacement can occur without flattening of the pars posterior. In contrast, a posterosuperior loading vector can lead to overstretching of the inferior stratum; this is always accompanied by a flattening of the pars posterior.

The superior stratum is responsible for the *timing of the repositioning.* The more this structure is overstretched the later the repositioning click occurs. In group 4 cases the click of an excursive movement is always terminal. The moment of occurrence is quick, simple, and reliably identifiable. Therefore when this occurs, the other groups (1, 2, and 3) can be immediately ruled out. In disk displacement with terminal repositioning it can be taken for granted that

- the superior stratum is badly overstretched and
- there is virtually no prospect of long-term success from conservative repositioning therapy. This is especially true if the retrusive click can be heard sooner at the intermediate or early terminal point.

The other possible cause of a group 4 click is *condyle hypermobility.* This normally noiseless overrotation past the crest of the articular tubercle occurs quite frequently (Oster et al. 1984, Johansson and Isberg 1991). Clicking sounds are associated with 10-22% of these cases and can be detected only if the movement occurs in combination with a deformed joint surface and an increased coefficient of friction due to changes in the synovial fluid (Tallents et al. 1993, Okeson 1998).

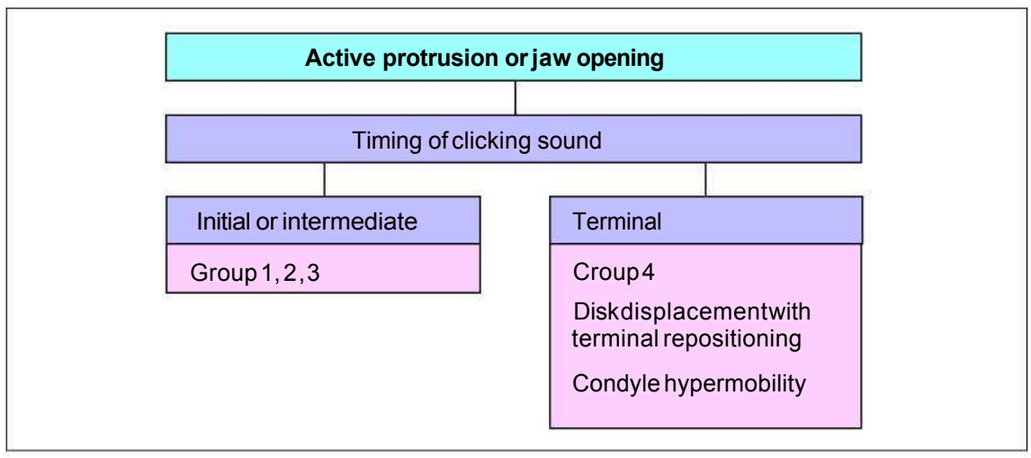
Group 1: Clicking Sounds from the Lateral Ligament or resulting from Disk Hypermobility

These clicking sounds occur during the initial or intermediate stages of active movement. A differential diagnosis must be made among groups 1, 2, and 3 (Fig. 287). Dynamic compressions are used to make this further differentiation.

When a clicking sound from the *lateral and/or medial ligament* is present, compression causes the sound to be diminished in intensity or disappear completely because the origin and insertion of the ligament are moved closer together. If a sound fails to reappear one must verify that the patient can open the mouth normally to rule out a disk displacement without repositioning. The timing of the click will be almost the same as during active movement. Thus the findings will be recorded as "softer click, same location" (Fig. 287).

In a case of disk *hypermobility* the clicking sound during the manipulated movement when compared with the click of the nonmanipulated active movement will be "softer and at the same location." Because a large portion of the disk still lies in a correct relation to the condyle and a broad area of the pars posterior is still convex, superior compression brings about a "centering" of the disk on the condyle. This causes the sound to be softer or, in some cases, to disappear altogether.

Since, as a rule, the click already occurs during the initial phase of active movement, hardly any change in the timing can be perceived with dynamic compression. One can also reverse the argument: As long as centering of the disk can be achieved through manual compression, the problem can be called a disk hypermobility. This indicates a lesser degree of structural damage than a manifest anterior disk displacement.



286 First differentiation with the aid of active movements
Through active jaw movement the examiner determines the timing (initial, intermediate, or terminal) of the clicking sound during the excursive movement (jaw opening, protrusion, or mediotrusion). When the timing of the sound is initial to intermediate, the condition is classified in group 1, 2, or 3. Terminal clicking sounds indicate a group 4 phenomenon.

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Group 2: Clicking Sounds due to Partial or Total Disk Displacement

Here too there is an initial to intermediate clicking sound during active movement and the differential diagnosis must again include groups 1, 2, and 3. Differentiation is accomplished through dynamic compression tests.

Partial disk displacement is basically a more advanced form of disk hypermobility. It is difficult to diagnose clinically whether 30%, 60%, or 80% of the disk is displaced, but all of these conditions are designated as partial displacements. Compression does not center the disk on the condyle as it would in a case with disk hypermobility, but rather the disk remains in its displaced position. Because compression narrows the joint space, greater tension is required in the superior stratum for repositioning. An increase in tension can only be generated by increasing the length, and therefore in a case of partial disk displacement the click will occur later under dynamic compression. Because of the spontaneous release of the stored up energy, the intensity of the clicking sound will be greater. This all results in a finding of "louder click, later timing."

With total disk displacement the same combination of findings emerges: the sounds become louder and occur at a later point. With advanced total disk displacement there is sometimes no clicking sound, but in these cases the jaw opening is always restricted in comparison with active movement. When that happens, the retrusive dynamic compression should be repeated with reduced superior pressure.

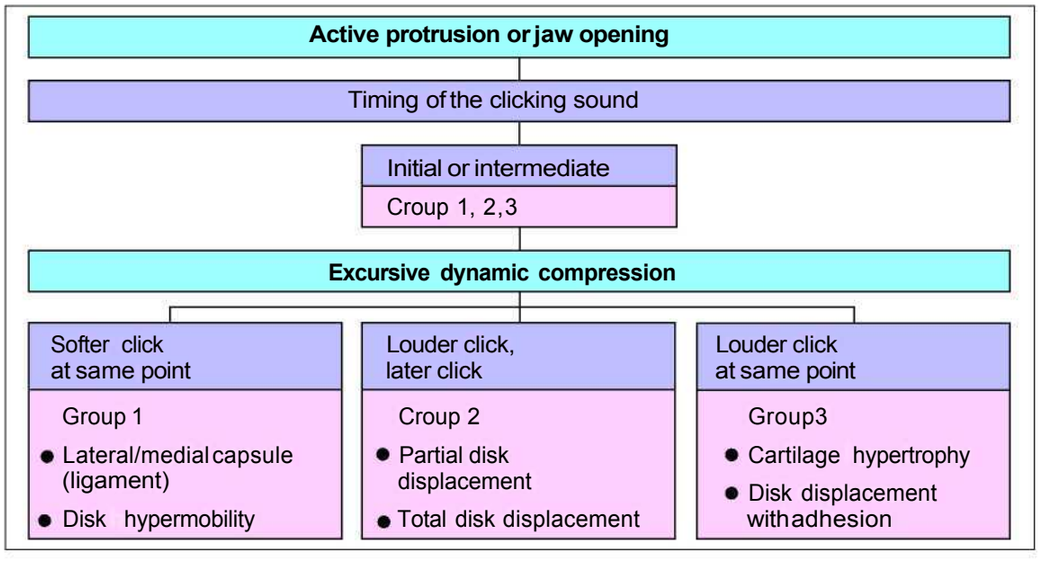
Group 3: Clicking Sound due to Disk Displacement with Adhesion or Cartilage Hypertrophy ("Deviation in Form")

During active movement the clicking sounds are always initial to intermediate and at the same point. Groups 1, 2, and 3 must be considered for the differential diagnosis, and dynamic compression is used for further differentiation.

Disk *adhesions* can be reliably diagnosed in the clinic only when they occur in combination with disk displacements. A combination of inflammatory exudate, fibrinogen, and hypomobility must occur before adhesions can form (Bewyer 1989). They occur more commonly in the upper joint space. Adhesions that occur without disk displacement can sometimes be recognized by a limitation of the protrusive movement (Holmlund and Axelsson 1996). Because of the restricted disk translation relative to the temporal bone, the clicking sound during manual translation occurs at the same point, but with greater intensity. The increased loudness is due to the decrease in the joint space under compression.

The term *"deviation in form"* means that there is an irregular joint surface. This occurs most often on the anterolateral portion of the protuberance and the condyle as well as on the centrolateral part of the disk (Solberg et al. 1985). In similar studies, about every other joint exhibits this type of change (Öberg et al. 1971, Hansson and Öberg 1977, Pereira et al. 1994a, b).

Deviations in form, however, are rarely the cause of clinically audible clicking sounds that can be clearly differentiated. On occasion, the click will occur during manipulated movement at the same point but with greater intensity than during active movement.



287 Differentiation among the groups
When there is an initial to intermediate clicking sound during active movement, the examination is always carried farther with dynamic compressions. By closely observing the two parameters, time of occurrence and intensity, and comparing them with the same for nonmanipulated active movement, useful information can be gathered for identifying the various groups. Clinically, group 2 is the most common type, accounting for 70% of clicking phenomena.

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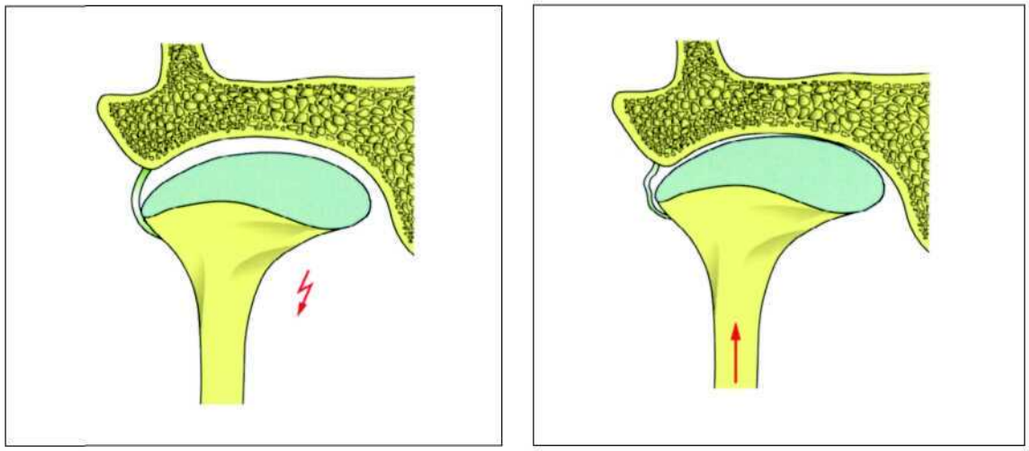
Differentiation within Group 1

Within group 1 a distinction can be made between clicking sounds arising from the lateral and/or medial ligaments and disk hypermobility. Disk displacement can occur in either the lateral (92%) or medial (8%) part of the joint. A differential diagnosis is accomplished through lateral and medial manual translation combined with compression. The test is begun with an isolated *lateral manual translation.* If the sounds that were heard during active movement now become louder, it is at least now known that the cause is located in the lateral portion of the joint, although it is not yet possible to differentiate between the two potential causes (ligament or disk).

If the sounds during lateral translation appear to be softer, a medial *manual translation* is performed. If this makes the sounds louder, the cause is in the medial portion of the joint. This is always followed by a translation with compression in the direction which made the sound became louder (Fig. 291). When *superior compression* is added, sounds from the ligaments will be softer and sounds from a hypermobile disk will become louder (Fig. 294). The direction of the translation tells us whether the sound is coming from the lateral or the medial side of the disk.

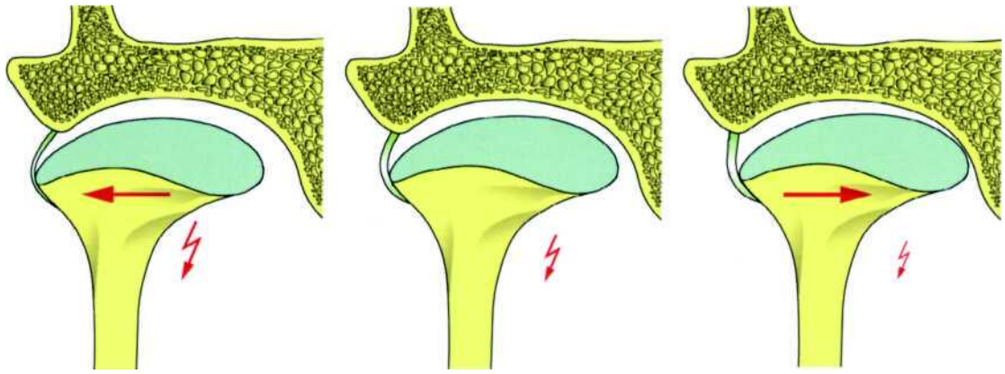


288 Clicking from the lateral ligament during dynamic compression

Frontal view of a right temporomandibular joint.

Left: There is a click in the joint during active movement. The intensity of the sound is indicated by the size of the crooked red arrow. For simplification the disk is omitted in these drawings.

Right: Manual compression relaxes the ligament and thereby decreases the intensity of the sound, but the timing of the sound is unchanged. Sometimes the sound will disappear completely.

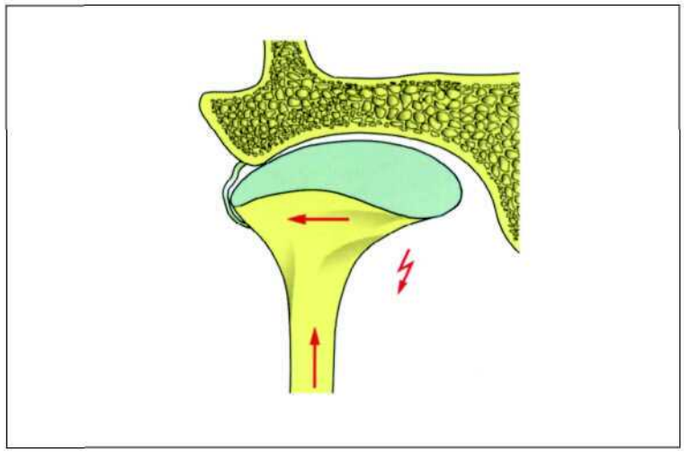


289 Clicking from the lateral ligament during manual translation

A Lateral manual translation: The ligament comes under greater tension and the intensity of the sound is increased.

B Starting position.

C Medial manual translation: The lateral ligament becomes relaxed and the sound becomes weaker. If there were a click from the medial ligament, the sound would become stronger (Fig. 291). Because further medial movement is limited by the anatomy, increased tension in the lateral ligament can be ruled out as a cause.



290 Clicking from the lateral ligament during manual translation with compression

Left: During a lateral manual translation with compression the sound is less striking than that from a pure lateral translation (Fig. 289 A). The same is true for a sound from the medial ligament during medial manual translation with compression.

Right: Example of an entry in the examination form for a clicking sound from the lateral ligament (see also Fig. 291).

Group I			
Lat+compr.		Med + compr.	
R	L	R	L
—			

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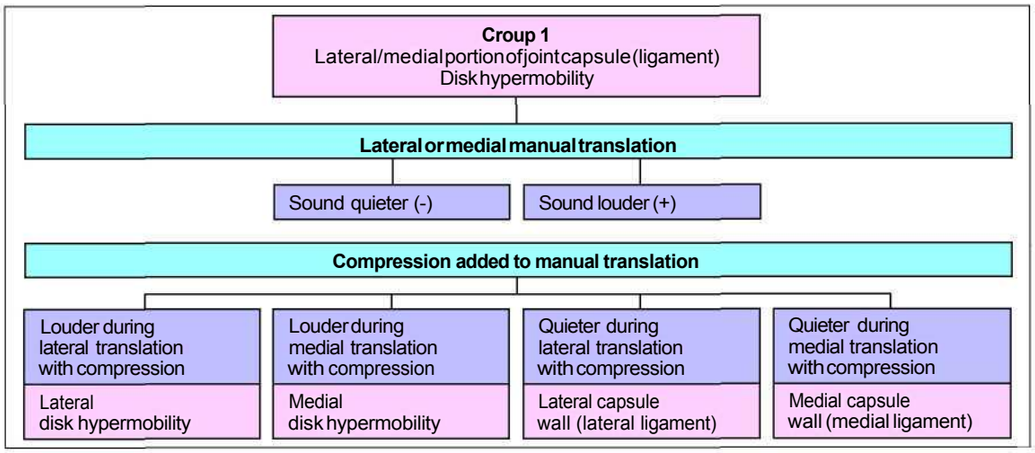
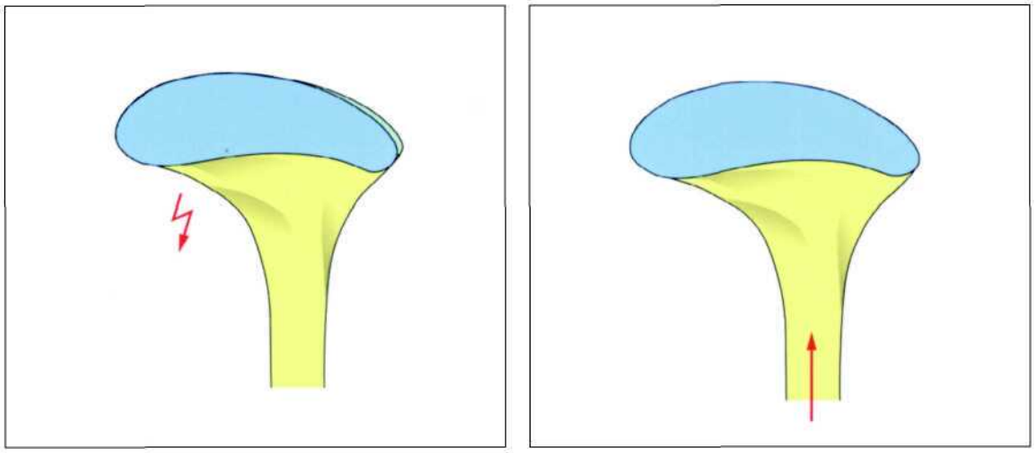
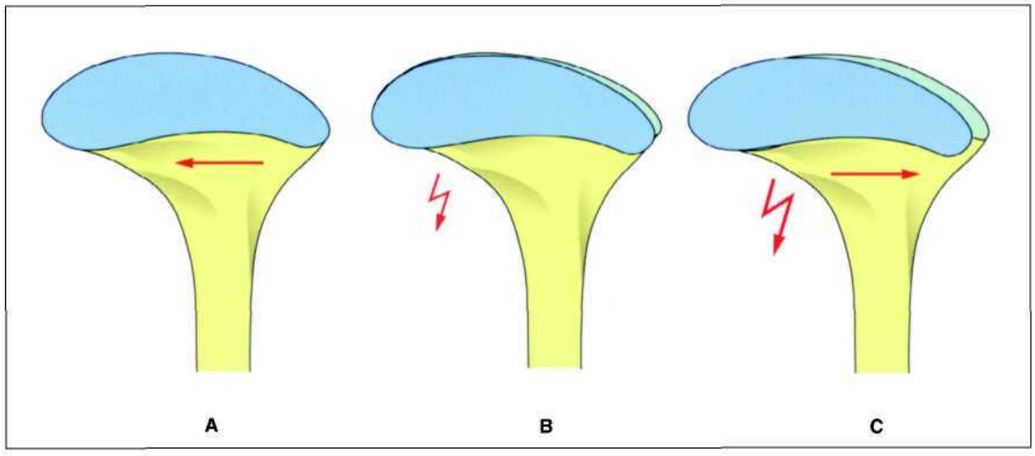


291 Systematic differentiation within Group 1
After the examiner has gone through the dynamic compressions in group 1, he/she proceeds with the differentiation though lateral manual translations and concludes by adding compression to those translations that produced loud sounds. In this way one can differentiate between clicking phenomena of the ligaments (= capsule) and disk hypermobility in the lateral or medial portions of the joint.



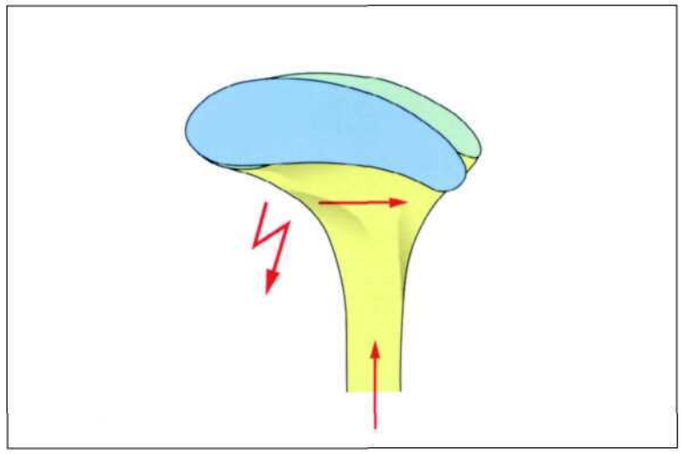
292 Disk hypermobility and dynamic compression
Left: With this condition there is usually an initial clicking sound during active movement. The anteriorly displaced portion of the disk (here the lateral portion) snaps back over the condyle as the jaws are opened. The crooked arrow symbolizes the intensity of the sound.

Right Manual compression prior to jaw opening centralizes the disk on the condyle causing the sound to weaken or disappear completely.



293 Disk hypermobility and manual translation
A Manual translation in the medial direction: The relation between disk and condyle is improved and the noise disappears.
B Starting position.
C Manual translation in the lateral direction: The relation becomes worse and the intensity of the sound increases.
If there were hypermobility of the medial portion of the disk, this translation would suppress the clicking sound (Fig. 291).

Group I			
Lat+compr.		Med+compr.	
R	L	R	L
+			



294 Disk hypermobility and manual translation with compression
Under lateral manual translation with compression the clicking sound becomes still louder than under pure lateral translation (Fig. 293 C). The effect would be the same for a medial manual translation with compression if the disk hypermobility were on the medial side.

Left: Sample chart entry for a disk hypermobility in the lateral portion of the joint (see Fig. 291).

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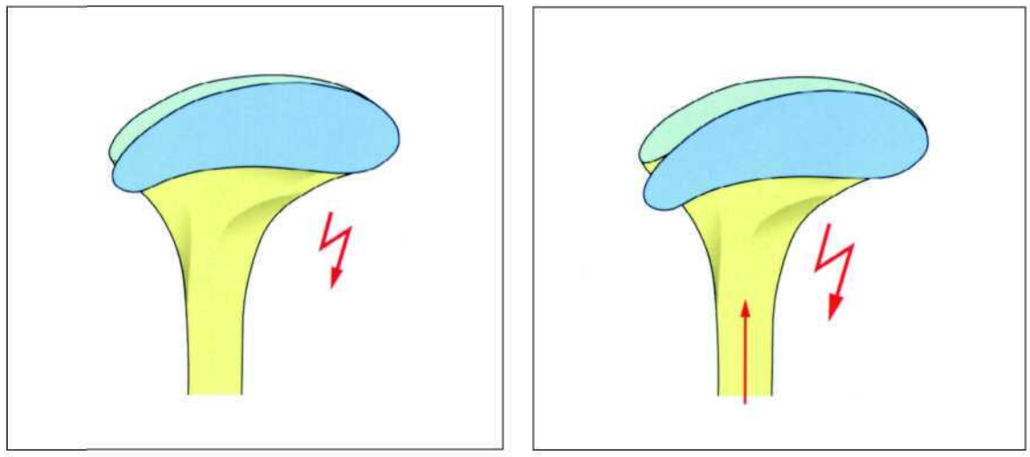
Differentiation within Group 2

Within group 2 a partial and a total disk displacement must be differentiated. MR images show that complete repositioning during jaw opening occurs in more than 90% of partial disk displacement cases, but in only 38% of total disk displacements. Because of this, the differentiation is of special therapeutic significance. *Lateral and medial manual translations* are used in making the differential diagnosis:

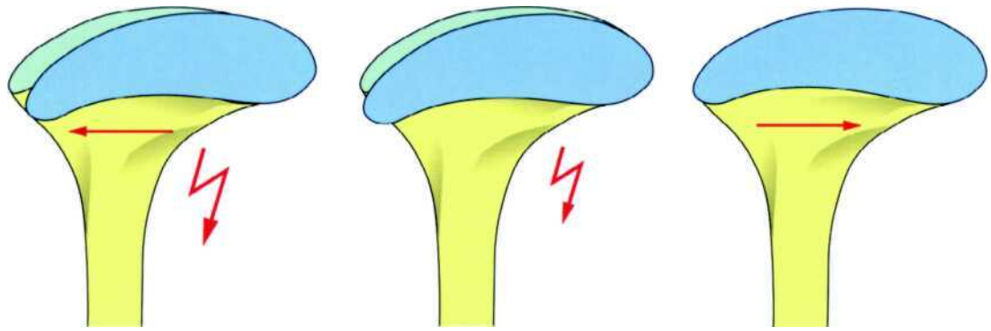
- With a *partial disk displacement* the click can be supressed in one direction of translation while it usually becomes louder in the opposite direction (Fig. 296). If during medial translation there is no longer a clicking sound, then there is a partial anteromedial disk displacement with repositioning. If the clicking sound can be avoided during a lateral translation, there is a partial anterolateral disk displacement with repositioning. In whichever direction of translation the click is absent, the disk still lies partially on the condyle.
- With a *total disk displacement* the clicking sound cannot be suppressed with a translation in either direction (Fig. 300).

295 Partial disk displacement
Left: Schematic drawing from an anterosuperior viewpoint of a right disk-capsule complex with a partial anterior disk displacement. The crooked red arrow symbolizes the sound intensity during active movement.

Right: Manual compression increases the amount of initial disk displacement, causing repositioning during jaw opening to occur later and more loudly.



296 Medial and lateral manual translation
A Lateral manual translation worsens the disk-condyle relationship, thereby increasing the clicking sound.
B Starting position before an active movement.
C Medial translation: In the presence of a partial anteromedial disk displacement the disk-condyle relationship is improved with lessening of the clicking sound. If there is a partial anterolateral disk displacement the results will be exactly the opposite.

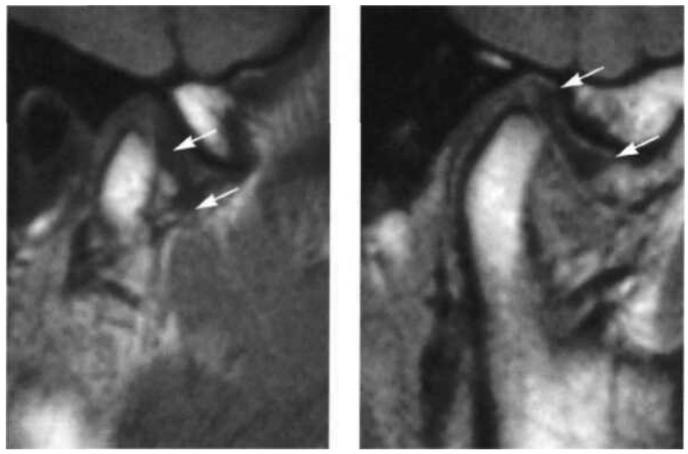


297 Partial anteromedial disk displacement in MRI
Left: In the lateral region of the right temporomandibular joint the disk (arrows) lies in front of the condyle.

Center: In the central plane the pars posterior (arrows) is still over the condyle.

Right: Examination form entry for the manual translation test of the right joint.

\+ louder click
0 no click



Croup II			
Lateral		Medial	
R	L	R	L
+		ϕ	

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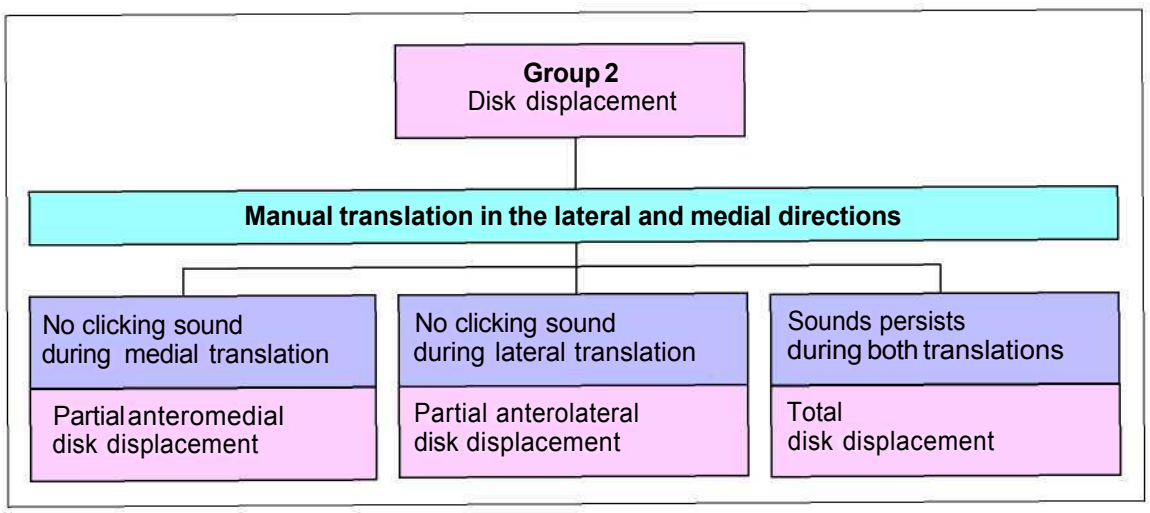
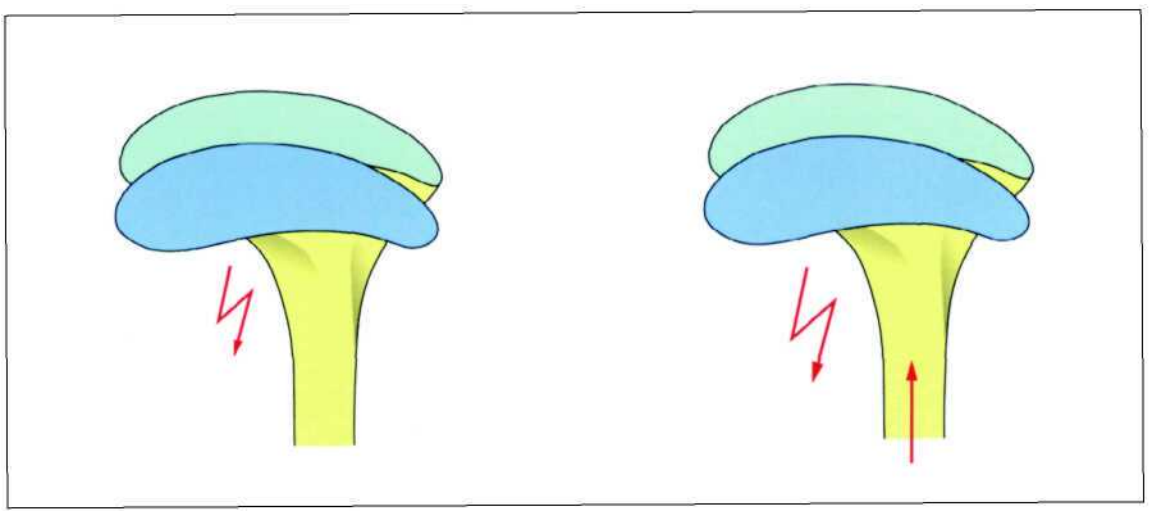
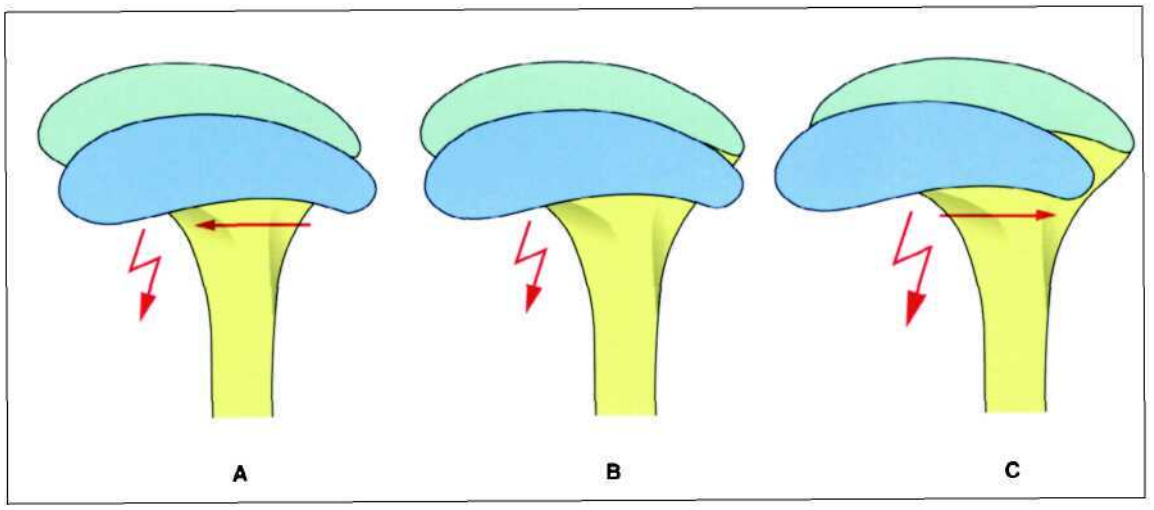


298 Flow chart for differentiation among group 2 clicking sounds
As soon as the dynamic compression tests have been completed in group 2 cases, medial and lateral manual translations are performed. Depending upon the individual findings, it may be possible to differentiate a partial anteromedial or anterolateral disk displacement from a total disk displacement.

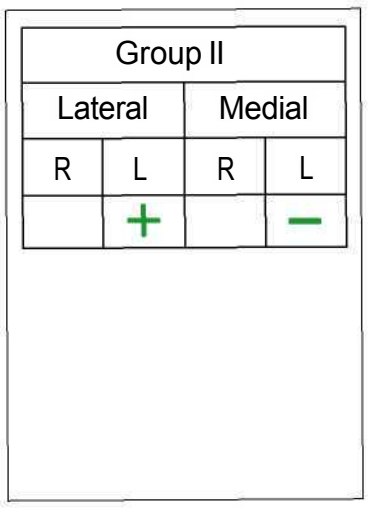


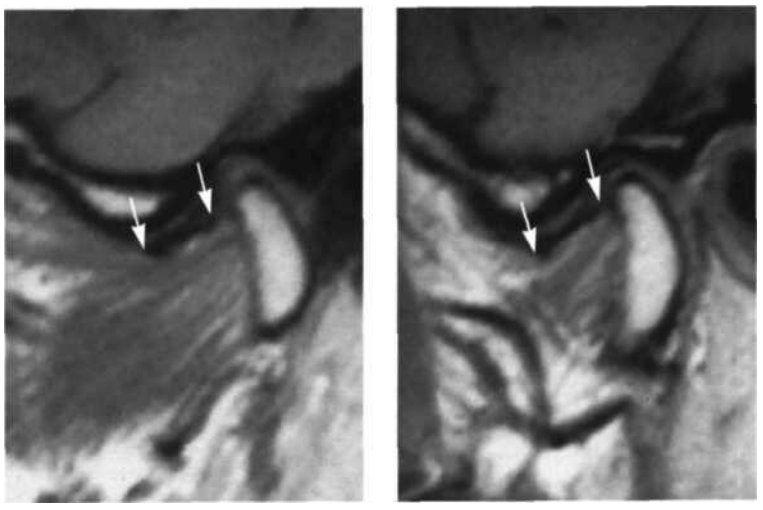
299 Total disk displacement
Left: Schematic representation from an anterosuperior viewpoint of a left disk-condyle complex with a total disk displacement. The crooked arrow represents the intensity of the sound during active movement.

Right: Initially a manual compression increases the extent of disk displacement, and the disk repositioning occurs later and louder during jaw opening. Too much pressure can simulate a nonreducing disk displacement.



300 Medial and lateral manual translation
The drawing in the center (B) represents the starting position before an active movement. When there is a total disk displacement neither a medial translation (A) nor a lateral translation (C) will significantly improve the relationship between disk and condyle. Therefore the clicking sound will persist in both directions of translation although it may be perceived as softer, louder, or the same in individual cases.





301 Total disk displacement in the left joint of a 53-year-old female patient
Left: Examination form for a manual translation test of the left temporomandibular joint. Neither of the two manual translations was free of clicking.

\+ louder click
\- softer click

Center and Right: MRI. In both the lateral plane *(right)* and the medial plane *(center)* the disk (arrows) lies in front of the condyle.

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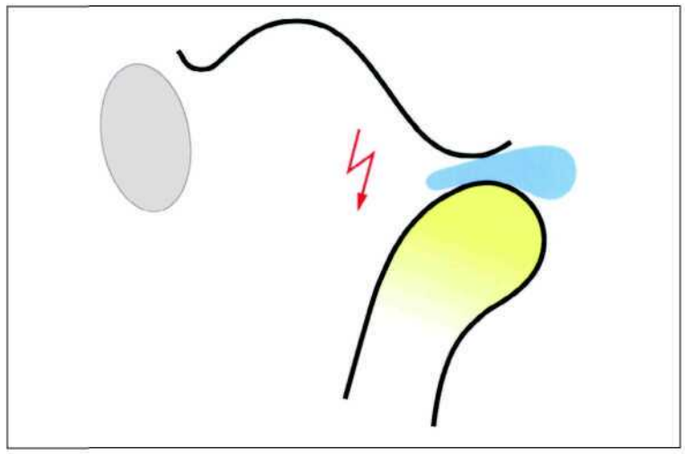
Differentiation among Unstable, Indifferent, and Stable Repositioning

The following tests are performed only if the previous findings within group 2 so dictate. In all other cases these procedures will provide no new information. Retrusion with dynamic compression (pp. 106,107) tests the *convexity of the pars posterior*. The three forms that can be differentiated are listed below with the corresponding diagnoses in parentheses:

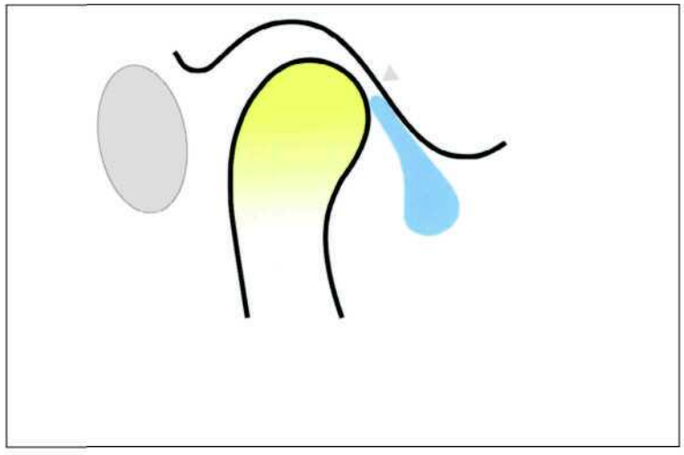
- Flattened wedge shape (disk displacement with unstable repositioning).
- Flattened on both sides (disk displacement with indifferent repositioning).
- Convex (disk displacement with stable repositioning).

Loading of the pars posterior causes both a stretching of the inferior stratum and a reduction in disk contour (Osborn 1985, Isberg and Isacsson 1986, Bell 1990, Müller-Leisse et al. 1997). This causes the disk to lose its ability to become centered under compression. As far as the etiology of disk displacement is concerned, a pars posterior need not necessarily become flattened; this depends essentially upon the direction of the loading vector. A purely posterior loading vector causes stretching of the inferior stratum without disk flattening, but displacement from posterosuperior loading is always accompanied by flattening of the disk.

302 Disk displacement with unstable repositioning after jaw opening
To test for flattening of the pars posterior the patient actively opens the jaws. During either the initial or intermediate phase of this movement the disk slips onto the condyle (= repositioning) and there is a clinically audible click. The patient then closes the mandible at the maximally protruded position. At this position the disk still lies over the condyle.

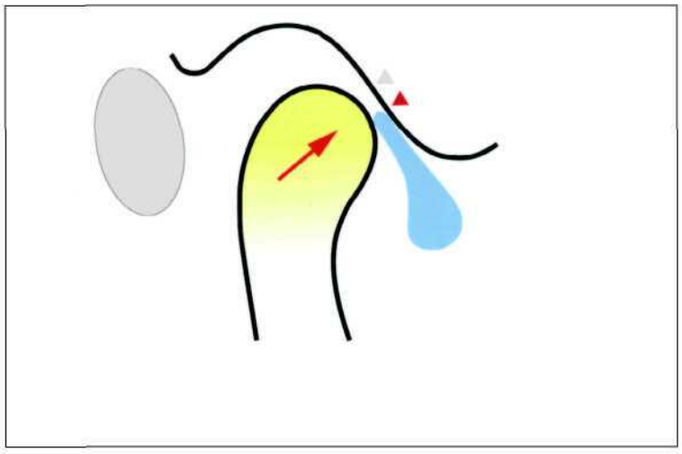


303 Disk displacement with unstable repositioning during active retrusive movement
From the position of maximal protrusion the patient now begins an active retrusive movement. At a certain point (gray triangle) there will be another click. For more accurate evaluation this position can be marked on the teeth (Fig. 281). This is the "active reference" for the subsequent test.



304 Disk displacement with unstable repositioning during retrusive dynamic compression
The patient opens the jaws to reposition the disk once more. This is followed by a posterior jaw movement under anterosuperior pressure (retrusive dynamic compression). If the disk is flattened posteriorly to form a wedge, the click will occur sooner during the course of movement (red triangle). From this information a diagnosis of "disk displacement with unstable repositioning" is made.

Right: Corresponding entry in the examination form.



Retrusive dynamic compression	
R	L
—	

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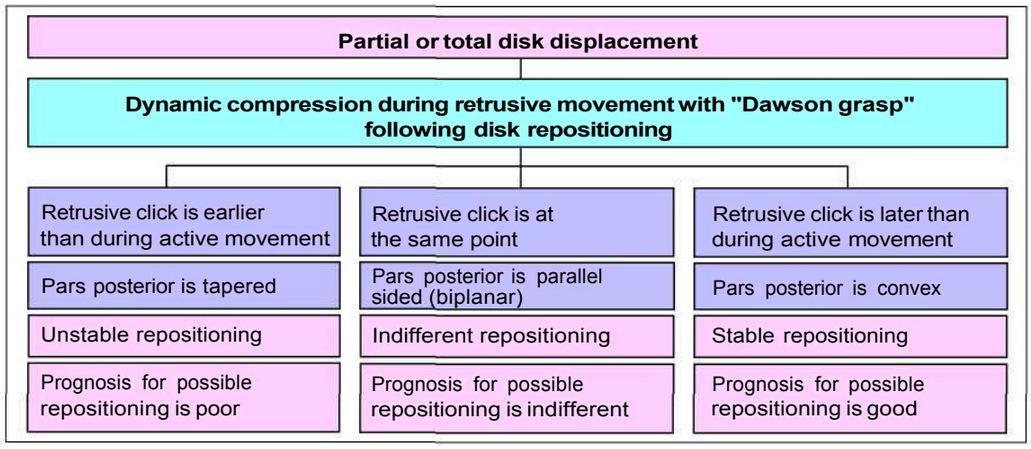
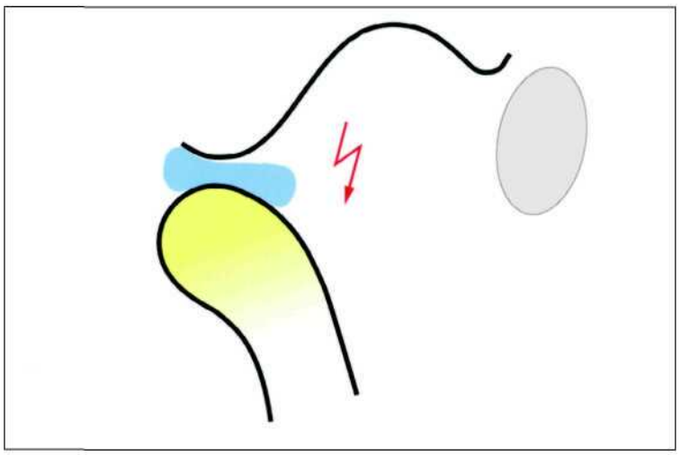
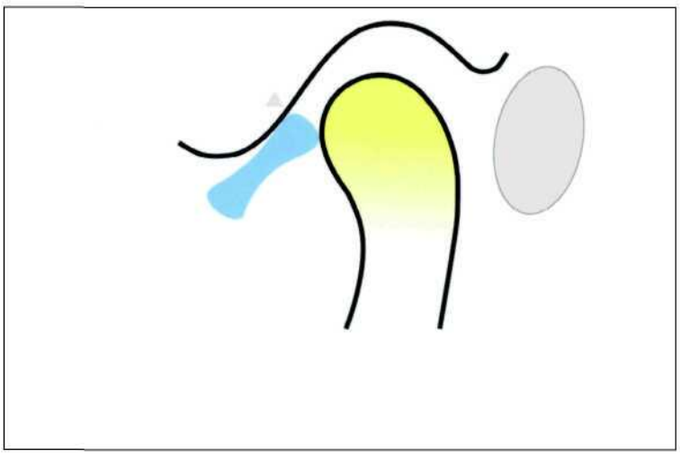


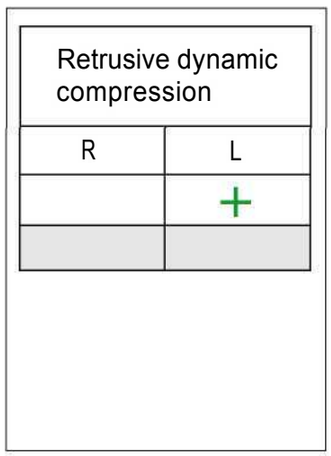
305 Systematic investigation of the shape of the pars posterior of the disk
These steps are followed only if indicated by the findings from active movements and dynamic compression in group 2 cases. This investigation provides better evaluation of the degree of deformation of the pars posterior (partial or total disk displacement) and also by classifying the repositioning as unstable, indifferent, or stable, allows better evaluation of the degree of damage to the disk-condyle complex.

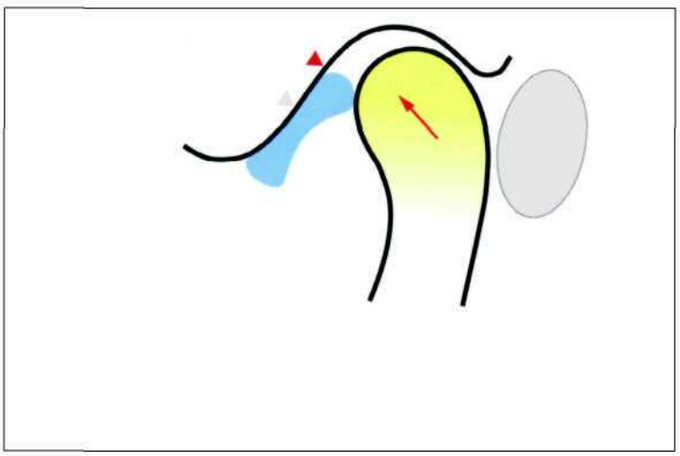


306 Disk displacement with stable repositioning following jaw opening
To test the convexity of the pars posterior the patient first actively opens the jaws. During this movement there will be either an initial or intermediate repositioning of the disk over the condyle accompanied by a clinically audible click. Next the patient closes the jaws in the position of maximal protrusion. At this point the disk is still positioned over the condyle.



307 Disk displacement with stable repositioning during active retrusive movement
From the position of maximal protrusion the patient begins an active retrusive movement which at a certain point (gray triangle) produces another click. This position can be marked on the teeth for a more accurate evaluation (Fig. 281) and serves as the "active reference point" for the remainder of the test.





308 Disk displacement with stable repositioning
After the disk is again repositioned by having the patient open the mouth widely, compression is applied in the anterosuperior direction as the patient moves the mandible posteriorly (retrusive dynamic compression). If the pars posterior is still convex, the clicking sound will occur later in the retrusive movement (red triangle) and the diagnosis is "disk displacement with stable repositioning."

Left: Corresponding entry in the examination form.

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Differentiation within Group 3

Within group 3 a distinction is to be made between a deviation in form and a disk displacement with adhesion. Here too the examiner makes use of *medial and lateral manual translations* to make the differential diagnosis according to the following rules:

- When there is disk displacement with adhesion the clicking sound becomes distinctly louder in at least one direction.
- When there is a deviation in form, the clicking sound does not, as a rule, become louder during manual translation.

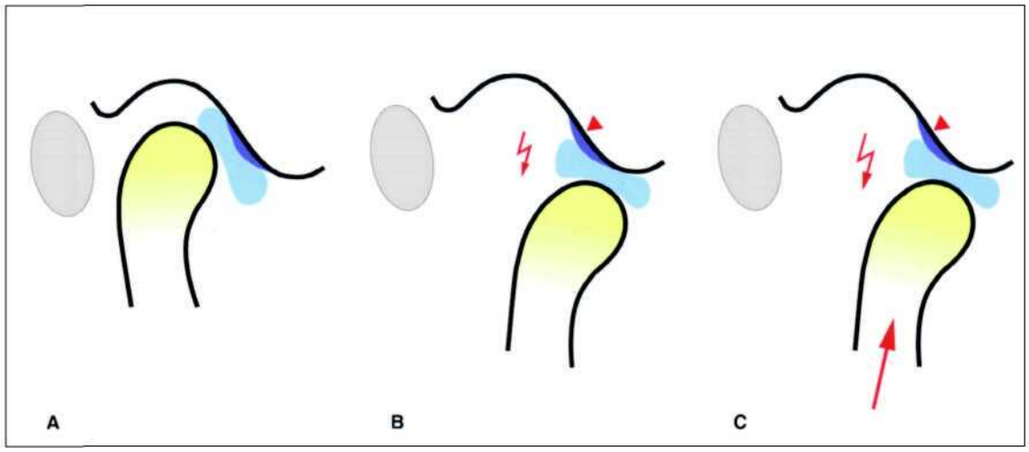
Regardless of the above, identification of a "deviation in form" will have little influence on the diagnosis and treatment because it rarely causes symptoms that can be reproducibly provoked and never requires treatment. Further diagnostic efforts concentrate therefore on disk *displacement with adhesion.* With the help of lateral and medial manual translations one can determine whether the disk displacement is partial or total. This information combined with the findings from passive compression tests allow one to determine whether or not the partial or total disk displacement with adhesion is accompanied by adaptation of the bilaminar zone. If the structures are well adapted there is no pressing need for treatment.

309 Deviation in form tested by active movements and dynamic compression

A With the teeth in habitual occlusion the disk-condyle relationship is almost normal.

B During active jaw opening the disk-condyle complex slides over the "deviation in form." The clicking sound *(4)* that occurs will be stronger or weaker depending upon how much the shape is altered.

C Under dynamic compression there will be an increase in the intensity of the palpable click, at least. The intensity of the audible sound is frequently unchanged.

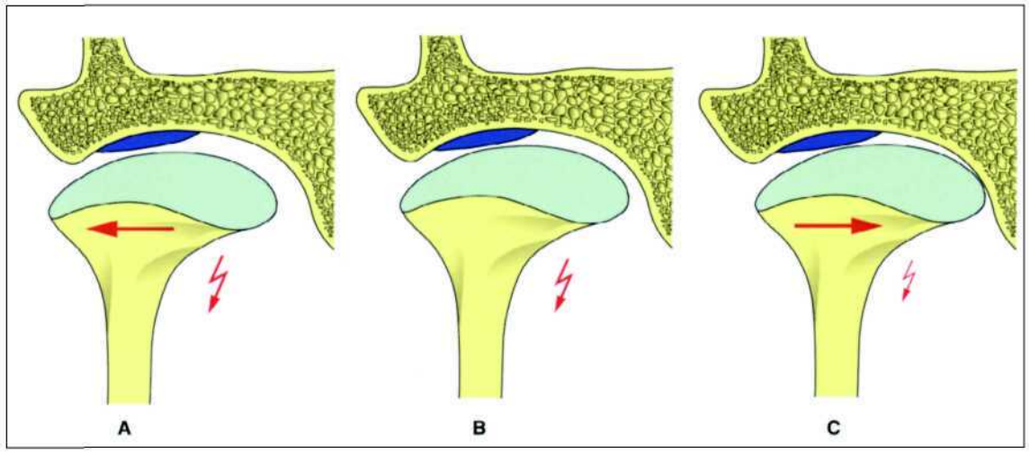


310 Deviation in form with manual translation

A Deviations in form are usually found in the anterolateral portions of the joint (Solberg et al. 1985). Lateral manual translation brings about only a slight change in the relation between the condyle and the abnormal convexity and has little effect on the intensity of the clicking sound (*4*).

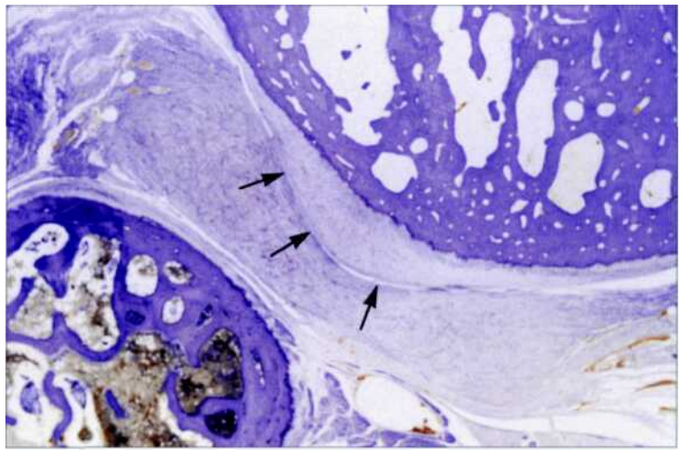
B Frontal view of the starting position. For simplicity, the disk is not depicted.

C During medial translation a reduction in sound can often be detected.



311 Morphological correlation and the examination form

A histological preparation from a 59-year-old subject. A deviation in form can be clearly seen on the articular protuberance (arrows). As the disk-condyle complex glides over this deviation there may be clicking sounds that can vary in intensity with the speed of movement.



Right: Example of a chart entry for a deviation in form.

Croup III			
Lateral		Medial	
R	L	R	L
ϕ		—	

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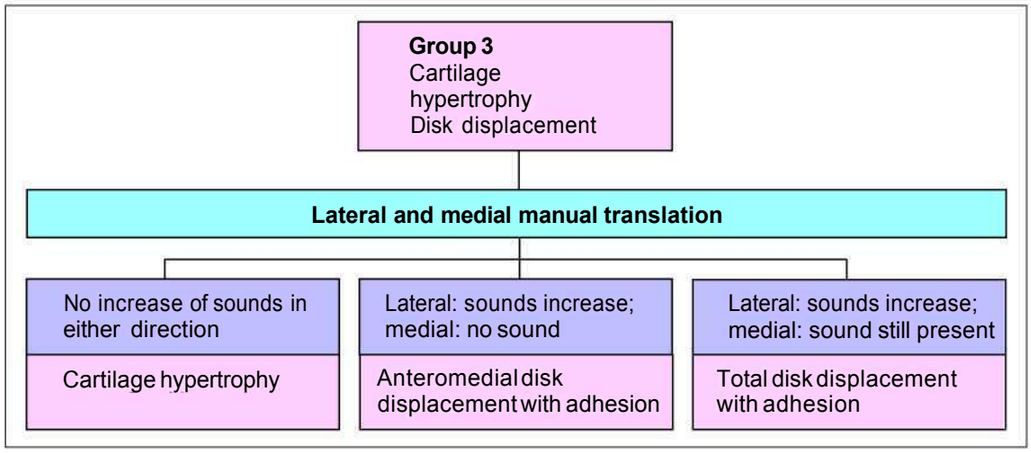
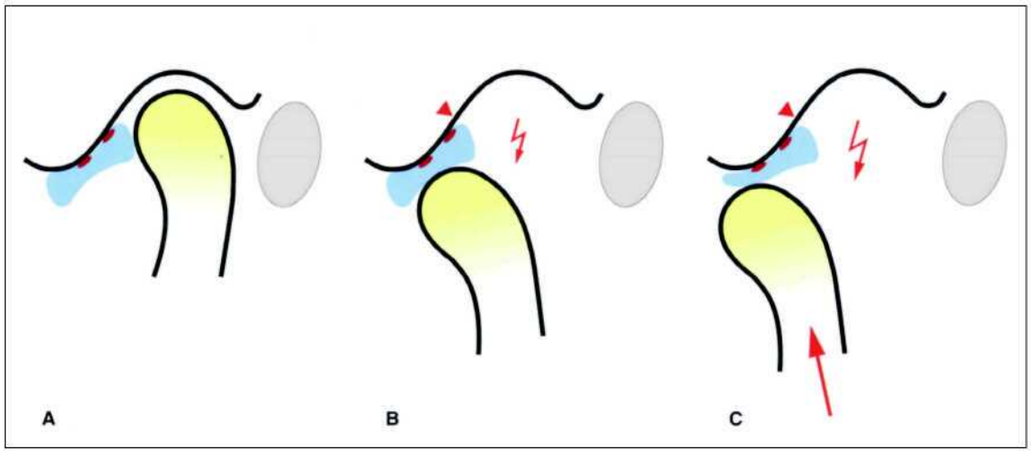
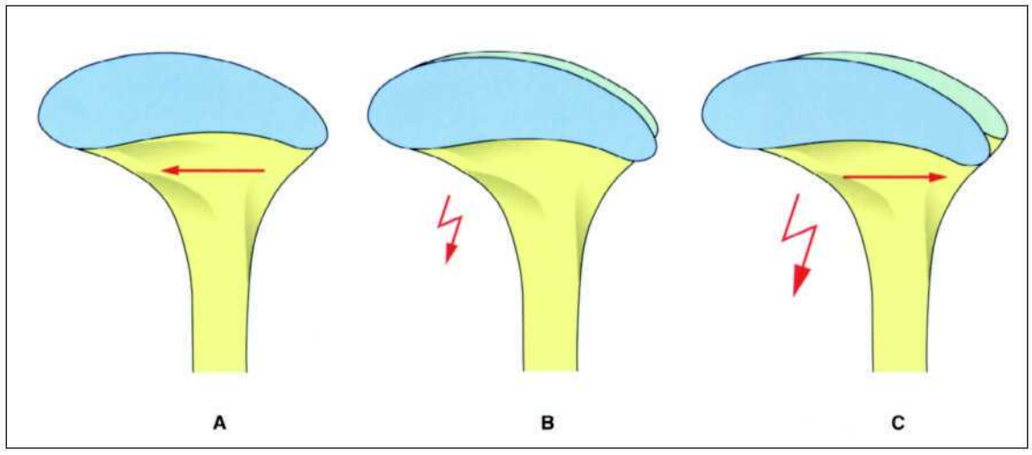


312 Flow chart for differentiating within group 3
If no definite clicking sounds are provoked in either direction during medial and lateral manual translation, a cartilage hypertrophy (deviation in form) is present. If a significant increase in the intensity of sound is brought about in one direction, there is disk displacement with adhesion. In this case, as in group 2, a further differentiation can be made between partial and total disk displacement with adhesion.

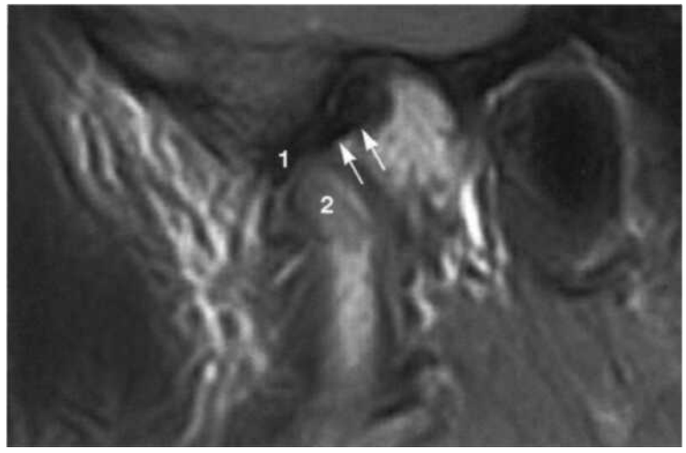


313 Disk displacement with adhesion tested by active jaw opening and dynamic compression
A In habitual occlusion the disk is partially or totally displaced in front of the condyle and is adherent to the temporal bone.
B During jaw opening the condyle snaps under the disk with a clicking sound (*4*).
C Under dynamic compression the intensity of the sound is increased because of the superior component of force, but its timing remains the same.



314 Disk displacement with adhesion tested by manual translation
A Under medial manual translation the disk-condyle relationship is improved and the sound is completely eliminated.
B Frontal view of the starting position for verification of a partial disk displacement with adhesion.
C Lateral manual translation causes a worsening of the disk-condyle relationship and significant intensification of the clicking sound

Croup III			
Lateral		Medial	
R	L	R	L
	+		ϕ



315 Morphological correlation and the examination form
MRI of a disk displacement with adhesion. In habitual occlusion the disk lies in front of the condyle. After jaw opening the condyle (2) lies against the pars anterior of the disk (1). The disk has undergone no change of position. Typical of a disk adhesion, a portion of the disk is projecting posteriorly (arrows).

Left: Sample entry in the examination form for an anteromedial disk adhesion.

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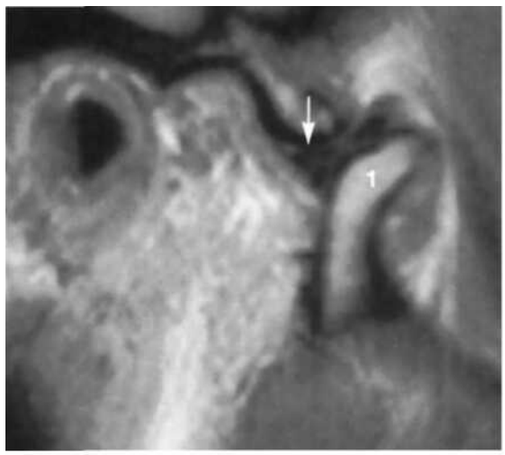
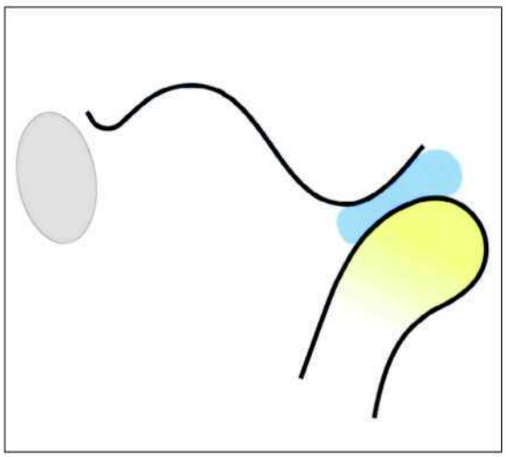
Differentiation within Group 4

Within group 4 a distinction is made between disk displacement with terminal repositioning and condyle hypermobility. For this the examiner uses a modified *retrusive dynamic compression.* This differentiation serves merely to provide the patient with an accurate explanation of the condition, because as a rule neither condition is treated. In both cases the clicking sound occurs at the end of the opening movement. The clinical differentiation is made more difficult by the fact that patients with a disk displacement with terminal repositioning frequently have condyle hypermobility as well. After maximal jaw opening, during which the click must occur, the examiner grasps the mandible in the same way as for a compressed retrusive movement. With this grasp, the condyles are guided posteriorly until they are just over the crests of the articular eminences. Beyond this point the examiner observes to see if a click occurs during further noncompressed retrusive movement of the condyles into the fossae. If there is no retrusive click the diagnosis is condyle hypermobility.

316 Active jaw opening with disk displacement and terminal repositioning
Left: To differentiate between the two phenomena of group 4 the patient must open the mouth to the maximum. The clicking sound that accompanies this is caused by either a disk displacement with terminal repositioning or by hypermobility of the condyle. At the end of the opening movement the condyle (1) is in front of the crest of the articular eminence (arrow) by a variable distance.

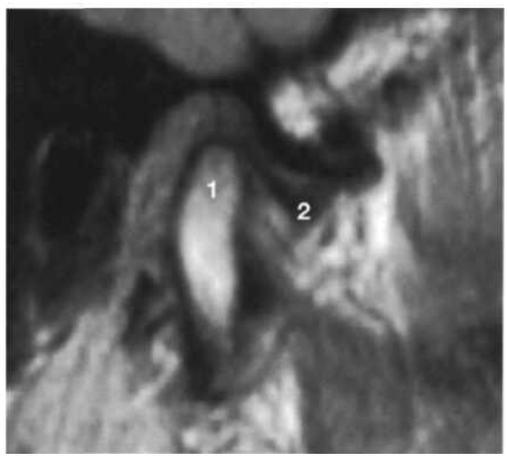
Right Schematic representation of the relationships found in the MRI.

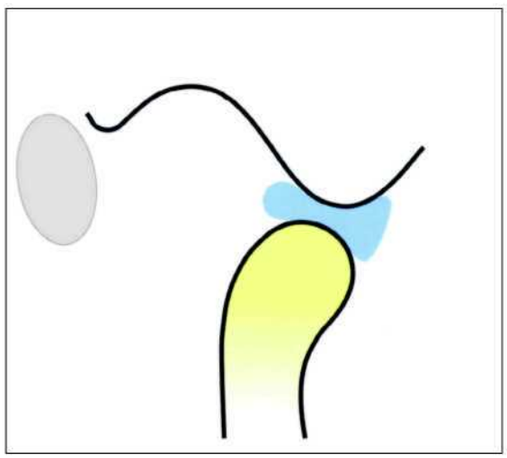




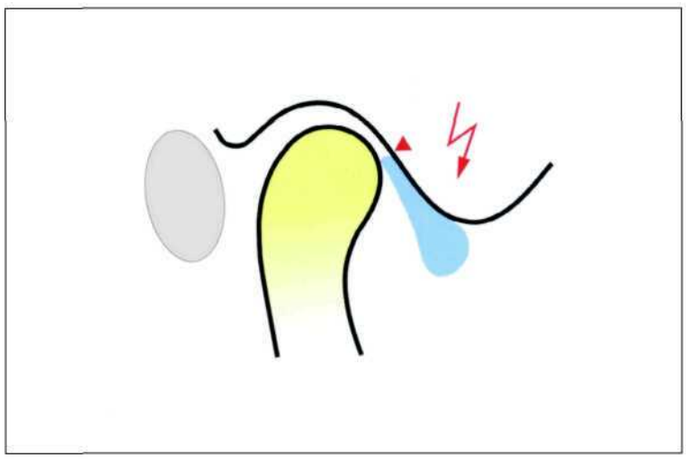
317 Guiding the condyle over the articular eminence in a case of disk displacement with terminal repositioning
Left Relation of the condyle (1) to the disk (2) shortly before the occurrence of the closing click.

Right The closing movement over the articular eminence is guided by the examiner using the same hand grasp used for retrusive dynamic compression (Fig. 284). Here, however, no anterosuperior pressure is exerted. The first part of the incursive movement progresses until the condyle has just passed the crest of the eminence.





318 Guidance into the fossa in a case of disk displacement with terminal repositioning
In the third phase of the differentiation procedure the condyle is guided back into the fossa with no anterosuperior pressure. A click during the movement of the condyle from the crest of the eminence to its final position in the fossa means that the disk has snapped off of the condyle. The diagnosis is "disk displacement with terminal repositioning."



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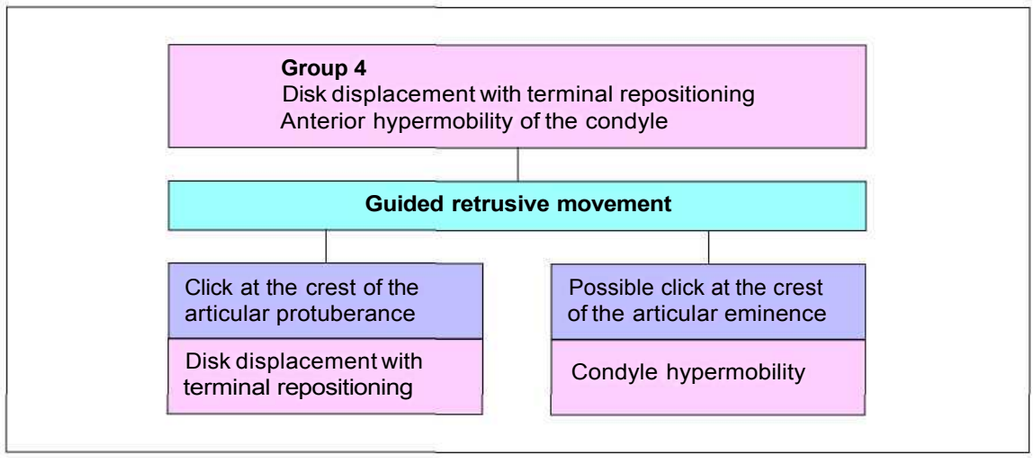
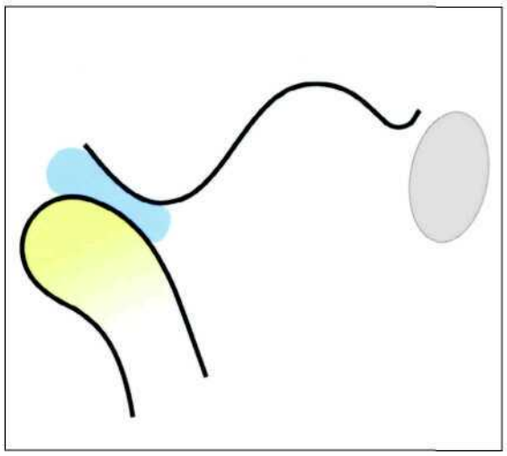
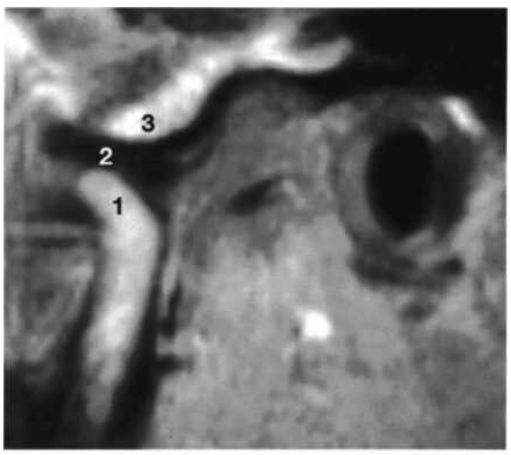


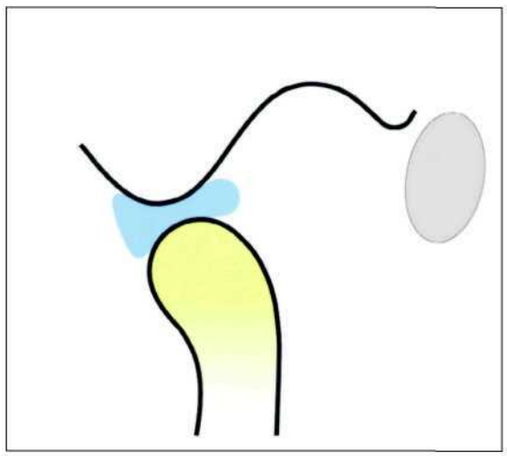
319 Flow chart for differentiating within group 4
There is no therapeutic advantage to differentiating between the two conditions in group 4 because, as a rule, neither phenomenon is treated. If a clicking sound occurs along the articular protuberance after maximal jaw opening, a disk displacement with terminal repositioning is present. Otherwise the diagnosis is hypermobility of the condyle.

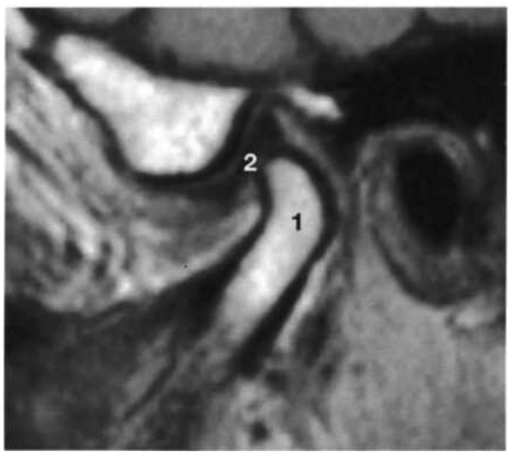




320 Active jaw opening in a case of condyle hypermobility
Left: If there is a terminal clicking sound during active movement, the patient must again open to the maximum for a differential diagnostic test. At the end of this movement the disk-condyle complex is anterior to the crest of the articular eminence. The amount of over-rotation can vary, as may also the amount of posterior movement of the disk relative to the condyle.

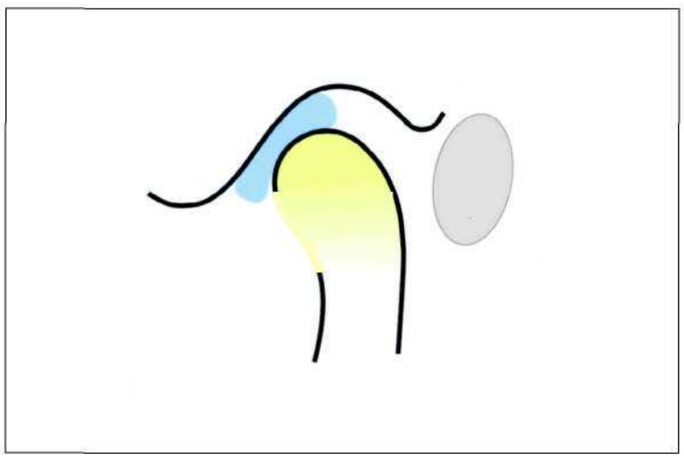
Right: Similar relationships on an MRI: condyle (1), disk (2), eminence (3).





321 Guidance over the articular eminence in a case of condyle hypermobility
Left: Starting at the position of maximal jaw opening the condyle is again slowly guided posteriorly over the articular eminence. Ordinarily there is never a clicking sound during this phase.

Right: MRI representation of the further posterior movement of the condyle along the protuberance. It can clearly be seen that the disk (2) still remains in a physiological position over the condyle (1). The MRI closely corresponds with Figure 322.



322 Guidance into the fossa in a case of condyle hypermobility
Schematic representation of the disk-condyle relationship at the end of the guided retrusive movement. If there is a click at the end of the opening movement but none during the following retrusive movement, the cause of the terminal opening click is a hypermobile condyle.

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Unified Diagnostic Concept and...

Only 43% of the clicking sounds found clinically through use of the conventional examination techniques (active movements and palpation of the sounds) correspond to the MRI findings (Paesani et al. 1992). This is one reason for our having developed over the past years the concept described on the preceding pages. For *treatment planning*, the dynamic test methods alone are quite inadequate for arriving at a correct understanding of the morphological destruction present. The unified concept is presented in Figure 323. In addition to the active movements and dynamic tests, an evaluation of the *bilaminar zone* and its degree of adaptation must be performed in every patient. The next extremely important step is the specific investigation into *the etiological factors.* In this connection, there must be present occlusal vectors (p. 126ff) in a posterior or posterosuperior direction if the displacement is to be treated in the centric condyle position. Otherwise, treatment must be carried out in a protrusive position determined by the therapist, and this is not neurophysiologically possible with every patient.

323 Unified concept for diagnosis of disk displacements and its therapeutic significance

On the preceding pages the necessity for active movements, dynamic compression, and dynamic translation was presented. In clarifying the etiological factors, it is important to determine not only whether occlusal vectors are present, but also whether there are other etiological factors at work (bruxism, dyskenesia, and blockade of the cervical spine). The greater the number of additional etiological factors that are present in the direction of the loading vector, the less favorable the prognosis for a strictly occlusion-based treatment.

One point that frequently fails to receive adequate consideration is the presence of musculoskeletal obstacles that restrict movement in the direction of treatment (p. 138f and 304). The more the capsule and the musculature have become adapted in the direction of the loading vector (p. 75), the more difficult the treatment will be and the greater the need for accompanying physical therapy. Testing of the tissue-specific parameters should be complemented by an evaluation of the occlusal position and the craniofacial construction. Jaw repositioning treatment requires much less effort with a skeletal class II or distoclusion than with a prognathic mesioclusion.

Furthermore, the need for other extensive orthodontic or prosthodontic treatment must be made clear to the patient. The more expensive the necessary collateral treatment will be, the stronger the case that can be made for repositioning treatment. It is basically true that repositioning treatment should keep the expense of follow-up occlusal treatment at a minimum, and this is not realized by every patient.

Examination protocol for patients with disk displacement

Technique	Objective
1 Active movements	Documentation and base of reference
2. Dynamic compressions, dynamic translations	Determination of the extent of displacement
3. Passive compressions	Determination of adaptive processes in the bilaminar zone
4. Clarification of contributing factors	Determination of the occlusal factors etc.
5a. Endfeel with traction and anterior translation	Determination of musculoskeletal impediments in the treatment direction
b. Isometric stretching of both lateral pterygoid muscles	See 5a.
c. Length of the suprahyoid structures	See 5a.

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...Treatment Plan for Anterior Disk Displacement

The treatment plan is based upon the clinical symptoms, the prognosis, and the expense of the treatment (Lous 1977). Pain in the temporomandibular joint is not proportional to the degree of disk displacement (Cholitgul et al. 1997), but rather to the adaptation capacity of the bilaminar zone. Therefore two forms of *adaptation* are necessary in repositioning therapy:

- fibrosis of the bilaminar zone for reduction of pain and
- regeneration of the inferior stratum for stabilization of the disk over the condyle.

Fibrosis of the bilaminar zone can be observed in 65-90% of temporomandibular joints depending upon the load vector. Therefore many patients have a high potential for adaptation. The more completely the loading factors (posterior and posterosuperior load vectors) can be eliminated, the more effective a repositioning treatment will be. Long-term studies have shown that a repositioning splint is not the ideal treatment appliance for a displaced disk (Moloney and Howard 1986, Okeson 1998). On the other hand, good results can be achieved with a Herbst appliance (Summer and Westesson 1997).

Decision parameters for treating displaced disks

Questions

	Yes	No
Partial disk displacement?	a	a
Stable reposition?	a	a
Adaptation of the bilaminarzone?	a	a
Occlusal influences?	a	a
Absence of other etiological factors?	a	a
Absence of musculoskeletal impediments?	a	a
Can the disk be repositioned in centric?	a	a
Angle Class II, no increase in craniofacial height?	a	a
Primary need for restorations?	a	a
Willingness to wear appliance or splint all day?	a	a
Can patient afford the time and expense?	a	Q

324 Clinical parameters for selection and prognosis of a repositioning treatment

Some indications for repositioning treatment are disk displacement with pain (Major and Nebbe 1997), diminished quality of life, and planned orthodontic treatment that will change the positions of the teeth regardless of whether or not repositioning is carried out. A further indication is the prospect of comprehensive prosthetic treatment in patients up to 45 years of age, because a repositioning attempt will not incur any additional occlusal follow-up treatment. The prognosis for a repositioning treatment depends upon the parameters listed in the table and, most of all, upon the treatment appliance. The questions in the box have been formulated so that a positive answer means a more favorable prognosis for the treatment. At the end the operator must weigh the positive and negative parameters, consider the treatment tools at his/her disposal, then decide whether or not it makes sense to attempt to treat the case.

The first three parameters are concerned with the morphological destruction, while parameters 4 through 7 evaluate the contributing factors. The last four can be regarded as general and social parameters.

If no pain is provoked by any of the joint manipulation techniques and no type of orthodontic or prosthodontic treatment is indicated, the dentist should be relatively reluctant to propose repositioning treatment for an adult.

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Tissue-Specific Diagnosis

Principles of Manual Functional Analysis

Symptoms arise in a biological system through an imbalance between the sum of the stressors acting upon it and the tissue's ability to adapt or compensate (see p. 2f). Because the adaptability cannot be directly increased, therapy must focus attention on reducing the etiological factors.

Approximately one in 10 18-year-olds has pain in the temporomandibular joint. Persons aged 20-45 years are those most commonly afflicted (LeResche 1997). In this age group it is most difficult for the adaptability of the tissues to keep up with the accumulation of etiological factors. Since adaptability cannot improve with advancing age due to the nature of cellular biology, the sum of etiological factors must become reduced beyond this age group. Otherwise it would be difficult to explain why older patients have fewer symptoms of functional disturbances in the masticatory system. These findings are in close agreement with the data from a MRI study of more than 1200 temporomandibular joints (Bumann et al. 1999).

325 Tissue-specific primary diagnosis
The primary diagnosis describes those symptoms the patient reported in the questionnaire (decompensated functional disturbances). A specific loading vector is also entered for each diagnosis. For every capsulitis the loading vector is already contained within the term. Every total disk displacement has a posterior or posterosuperior loading vector, and every partial displacement has a posterolateral or posterosuperolateral vector.

Tissue-specific primary diagnoses		Loading vector		Clinical influences							
				Stat. occl.		Dyn.occl.		Bruxism		Dysfunction	
Right	Left	Right	Left	Right	Left	Right	Left	Right	Left	Right	Left

Pain is an important protective mechanism. Because of pain, the stressors acting on the structure are reduced and the reduced adaptability of the affected structure can "catch up." Many studies have been concerned with the role of occlusion as a cause of functional disturbances. Normally, however, there are only 18-32 minutes of tooth contact each day (Graf 1969, Haddad et al. 1974). Overloading of the temporomandibular joints occurs, therefore, only when the musculature and the occlusion are used with a nonphysiological frequency. Because of this, the occlusion should not be viewed solely as the initiator of symptoms, but more as a protective mechanism for the joints.

Nevertheless, if during a particular phase of life the occlusion is "used too often," then this should take place in a position that will not produce loads damaging to the joints. Because 70% of the pain symptoms appear in the posterolateral and posterosuperolateral directions (Bumann et al. 1999), it is especially important that these two directions be protected by the occlusion. Therefore the goal of a prevention-oriented dental practice must be to contribute to safeguarding the adaptation capacity of the masticatory structures by creating or preserving a physiological occlusion.

A cause-oriented therapy requires that the operator knows *what* the patient is suffering from *(tissue-specific diagnosis, loading vector)* and why *(identification of etiological factors).*

The following serve to determine the loading vectors:
- the pain protocol
- the protocol for differentiation of limitations of movement
- the clicking sound protocol and
- the routine protocol.

The detection of a loading vector is possible clinically only through manual functional analysis.

If there is a loading vector, a search is made for stressful influence vectors in the same direction. The etiological factors relevant to dentistry include (pp. 124ff):
- the static and/or dynamic occlusion
- bruxism
- dysfunctions.

The etiological factors are determined through a clinical or instrumented occlusal analysis (pp. 201 ff). Without knowledge of a specific loading vector, the conclusions that can be drawn from an instrumented analysis are limited.

Protocol for Cases with Pain (pp. 68ff)

Investigation of pain begins with an intraoral examination to rule out a periodontal or dental origin. Next, the joint surfaces are examined using dynamic compression and four different dynamic translation tests.

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These five techniques provide information about any osteoarthosis or osteoarthritis in the lateral and medial portions of the temporal and condylar joint surfaces.

These are followed by the seven techniques of passive compression for testing the *bilaminar zone.* Reproducible, provokable symptoms are designated as capsulitis with the corresponding loading vector. *Translations* and *traction* are used to test the degree of adaptation of the capsule. Painful responses are described as capsulitis with the specific loading vector. Finally, any painful lesions in the musculature are investigated through *isometric contractions.* The advantages of isometrics have been thoroughly discussed. If none of these techniques succeed in provoking the patient's specific pain, it cannot be treated by cause-oriented dental therapy.

Protocol for Limitations of Movement (pp. 631 ff)

Limitations of movement can be adequately tested only if they are free of pain. In these cases the examiner can evaluate the limiting structures by determining the *endfeel.* If the technique for determining the endfeel has not been mastered, the differential diagnosis can only be pursued *ex juvantibus.*

Tissue-specific secondary diagnoses		Loading vector		Clinical influences							
				Stat. occl.		Dyn.occl.		Bruxism		Dysfunction	
Right	Left	Right	Left	Right	Left	Right	Left	Right	Left	Right	Left

326 Tissue-specific secondary diagnoses
Secondary diagnoses are based upon signs and symptoms that the patient did not report but that can be repeatedly provoked (compensated functional disturbances). Again, the specific loading vector is entered for each diagnosis: joint surface lesions have anterosuperior loading vectors and muscle lesions always have vectors in the direction of their contraction.
Only after this has been done is the examination continued with an evaluation of the etiological factors.

Protocol for Clicking Sounds (pp. 98ff)

Investigation of clicking sounds is performed with *dynamic compressions* and *dynamic translations.* Causes of clicking sounds are various forms of disk displacement (70%) or phenomena connected with the lateral ligament, disk adhesion, or condylar hypermobility. The differential diagnosis must distinguish among eight phenomena in four groups. Differentiation among the groups is accomplished through *dynamic compressions.* Dynamic translations then serve to differentiate within the groups. The decision to treat a disk displacement depends chiefly upon the symptoms evoked through *passive compressions* (pain in the bilaminar zone!) and 10 additional parameters. The greater the changes that have occurred in the inferior stratum of the bilaminar zone and the pars posterior of the disk, the poorer the prognosis.

Routine Protocol (p. 140)

During the examination of a routine patient who is not concerned about a temporomandibular joint problem, but who is seeking orthodontic or other dental treatment, the procedure follows the same principles. Essentially, the routine examination should answer three sets of questions:
- Is a compensated loading vector present?
- Are there restrictions of movement in the system?
- Is a static and/or dynamic occlusal vector present?

Only some of the techniques discussed are necessary to evaluate a loading vector (see also p. 140). Identification of factors that could impede the treatment (restrictions of movement) is useful only if the position of the mandible is to be changed as part of the dental treatment. Otherwise the examination only represents a prophylactic measure. The clinical testing of static and dynamic occlusal vectors will be described in detail on pages 124ff.

Primary and Secondary Diagnoses

At the end of the tissue-specific examination, the so-called primary and secondary diagnoses are entered. Primary *diagnoses* include all decompensated functional disturbances that explain the symptoms reported by the patient. Secondary diagnoses are compensated functional disturbances that explain the symptoms that could be repeatedly provoked during the examination. For each individual diagnosis, the clinician records the specific loading vector on the examination form. Clarification of the etiological factors cannot begin until this has been done.

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Investigation of the Etiological Factors (Stressors)

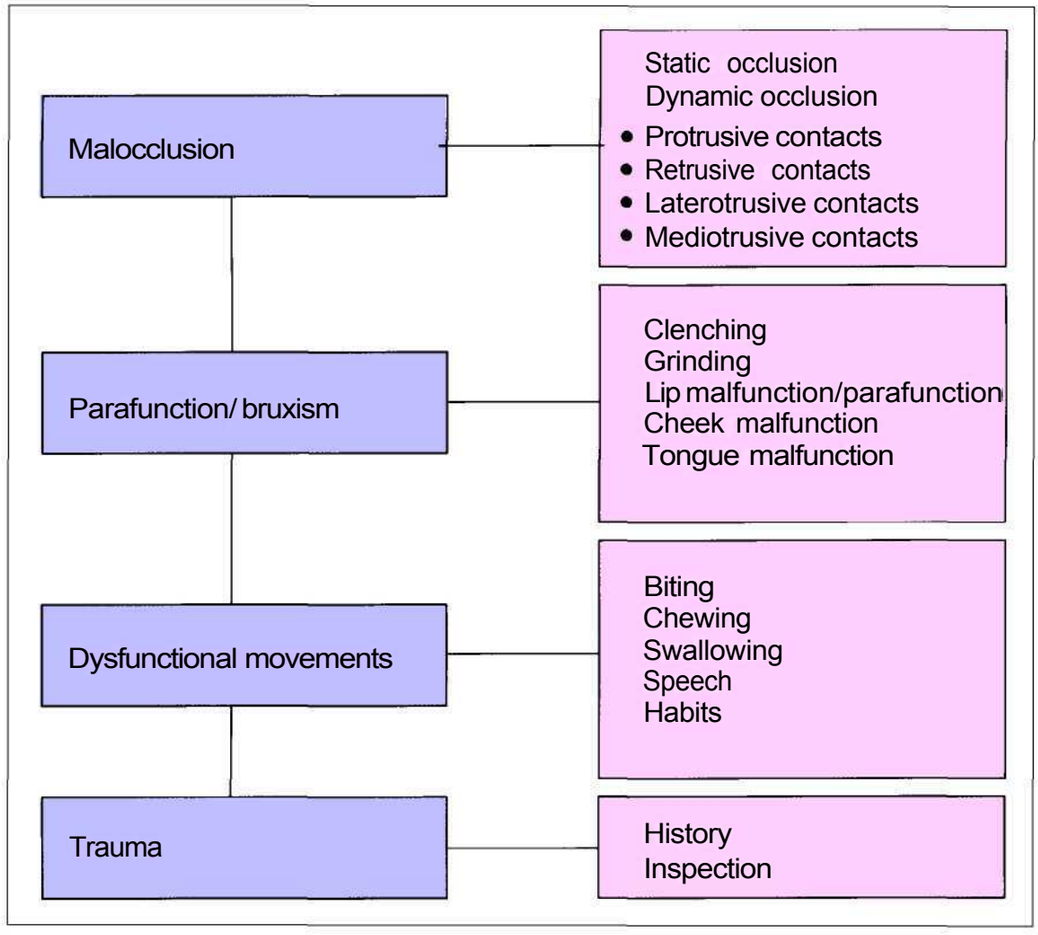
If a patient has a *nonspecific loading vector,* it makes no sense to test for etiological factors at that point in time. Instead, the next step should be to begin nonspecific pain therapy such as insertion of a stabilization splint and possibly administration of medications (see p. 303).

A patient with a *specific loading vector* must be examined for etiological factors before being treated so that a causal correlation between the discovered loading vector and any "static" or "dynamic occlusal vector," a "bruxism vector," or a "dysfunction vector" can be demonstrated. How these vectors are diagnosed clinically will be explained on the following pages. Whenever any of the vectors just mentioned point *in the same direction* as the loading vector, there is a causal connection between the functional disturbance (= loading vector) and the current etiological factor. If one or more vectors of stress are present but do not point in the same direction as the loading vector, a cause-oriented treatment through modification of the occlusion is not possible.

327 Schematic procedure
The diagram shows the sequence of steps in the systematic investigation of the etiological factors.

- With reference to the *occlusal* influences (vectors) a strict distinction must be made between the static and dynamic occlusion.
- The group *parafunction/bruxism* encompasses predominantly the static neuromuscular functions and malfunctions.
- The group *dysfunctional movements* includes mainly the dynamic processes.

The etiological factors listed here can be tested for clinically and also with the aid of paraocclusal electronic axiography. The static occlusion can also be studied on instruments for condylar position analysis. Each method has its advantages and disadvantages, but adequately meets the clinical demands.



Under no circumstance should an occlusal vector be confused with a sliding movement initiated from a manipulated retruded mandibular position (Piehslinger et al. 1993, Clark and Evans 1998). In a symptom-free, fully adapted patient, a manipulated retruded mandibular position may be used as a trial position for an extensive prosthetic restoration. It is not, however, indicated for revealing a specific static or dynamic occlusal vector.

The magnitude of an occlusal vector does not allow it to be classified as either "acceptable" or "unacceptable," but merely indicates what proportion of the overall loading vector it constitutes. In patients with myogenic pain, the direction of the occlusal vectors seems to play a subordinate role (Visser et al. 1995b).

The clinical procedures for a systematic investigation of the etiological factors can be classified as follows:

- Neuromuscular deprogramming.
- Testing the static occlusion.
- Testing the dynamic occlusion.
- Investigation of parafunctional influences.
- Investigation of dysfunctional influences.

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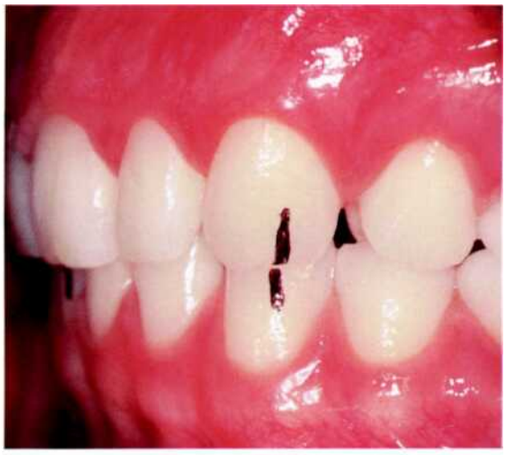
Neuromuscular Deprogramming

Before a test for static or dynamic occlusal etiological factors is conducted, it is necessary to deprogram the neuromuscular system to clear away any neuromuscular engrams that may have been introduced. Through deprogramming, the neuromuscular system is given the opportunity to place the mandible in a position independent of the occlusion. When the structures of the masticatory system are in a physiological condition, the resulting mandibular position is influenced only by the activity of the antagonistic muscle groups attached to the mandible. A number of deprogramming techniques are being used in dentistry prior to making a centric registration, although their actual effectiveness has not yet been tested scientifically. Among these are:

- Relaxation on cotton rolls or an anterior bite jig.
- Relaxation on an Equalizer.
- Use of the Myo-monitor.
- Use of acupuncture (Rested 1998).
- Use of hypnosis.
- Use of biofeedback procedures.
- Opening and closing movements without tooth contact



328 Markings in habitual occlusion
Left: To more easily evaluate the change that will be brought about by neuromuscular deprogramming, the midline and starting vertical overlap are marked. If the upper and lower midlines are coincident in the habitual occlusion, this step can be skipped.

Right: To better judge changes in jaw position in the sagittal plane, marks are also made in the canine or premolar region.

329 Neuromuscular deprogramming
Left: Wide opening and closing movements repeated 10-15 times have proven to be a quick and efficient method for neuromuscular deprogramming.

Right: The teeth must not be allowed to make contact during the closing movements, otherwise the masticatory system will immediately fall back into the customary pattern of movement. The centric condylar position is determined from this starting position.

Deprogramming can have a significant effect on the position of the mandible only if

- there is truly a discrepancy between the nonmanipulated centric and habitual centric condylar positions;
- there are no musculoskeletal impediments (constrictions of the muscles or the joint capsule).

Furthermore, acute pain in the masticatory system can influence the mandibular position (Obrez and Türp 1998), making the evaluation of any occlusal vectors that might be present more difficult.

At this point in the examination the musculoskeletal impediments as well as the loading vectors of acutely painful altered structures are already known because of the findings of the endfeel test during traction and anterior translation, determination of the length of the suprahyoid musculature, and the findings of the joint play tests for differentiation of pain. In the presence of pain-free musculoskeletal impediments the dentist has the option of determing the "true centric" through a systematic decompression treatment (p. 312) or restoring the patient's occlusion in the so-called adapted condyle position (Dawson 1995), leaving any existing loading vectors untreated because of the patient's high level of adaptability.

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Mandibular and Condylar Positions

The preceding presentations have made the clinical significance of an occlusal vector clear. The point of the vector is determined by the habitual occlusion. This is, as a rule, reproducible and well suited as a reference position (Ingervall 1968). Both the magnitude and the direction of an occlusal vector and the etiological and therapeutic consequences deriving from it therefore depend essentially upon the starting position of the mandible.

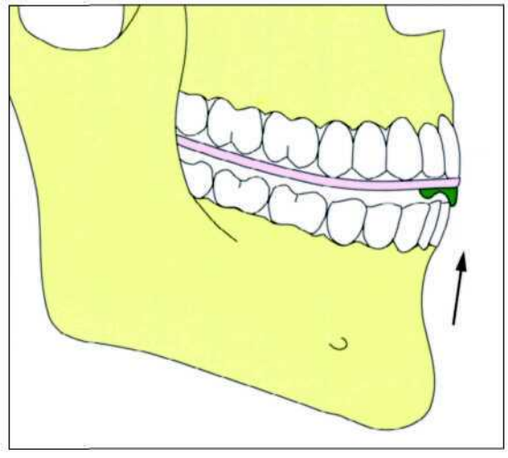
As numerous studies on different patient populations have shown, a definite, universally valid, anatomical condylar position cannot be demonstrated either on asymptomatic test subjects or on patients with pathologically altered temporomandibular joints (Pullinger et al. 1985, Alexander et al. 1993, Ren et al. 1995a,b, Braun et al. 1997). Consequently, one cannot regard the *centric condylar position* as a static, fixed anterosuperior position of the condyles as it has often been described in proposed definitions and nomenclatures (Freesmeyer et al. 1992, van Blarcom 1994). Rather, it is that condylar position which must result in each individual patient when the antagonistic muscle groups of the mandible act symmetrically with a minimum level of mus-

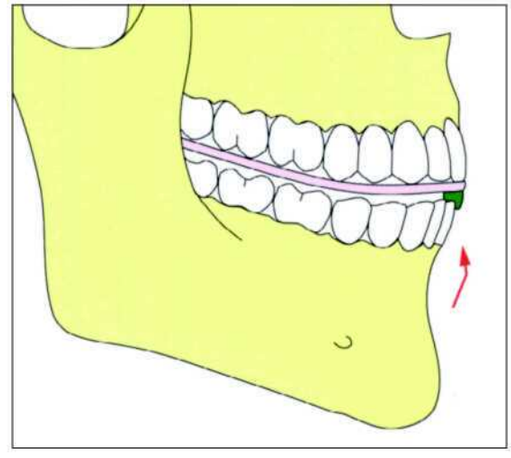
330 Pronounced occlusal instability
Left: Following the neuromuscular deprogramming, the patient is asked to gently close the jaws until the first minimal tooth contact is felt, and to point from outside the mouth to the primary contact.

Right: Following renewed opening and closing movements the procedure is repeated. If the patient repeatedly points to different primary contacts, she is currently exhibiting pronounced occlusal instability and splint therapy should be instituted.

331 Slight occlusal instability
Left: If a patient does not exhibit a pronounced lack of coordination, an attempt is made to make a reproducible centric registration (see p. 211). After the formation of an anterior bite jig, neuromuscular deprogramming is again performed and the three-dimensional relationship of the mandible to the jig is tested. In the example shown here, the lower incisors touch the anterior slope of the jig first.

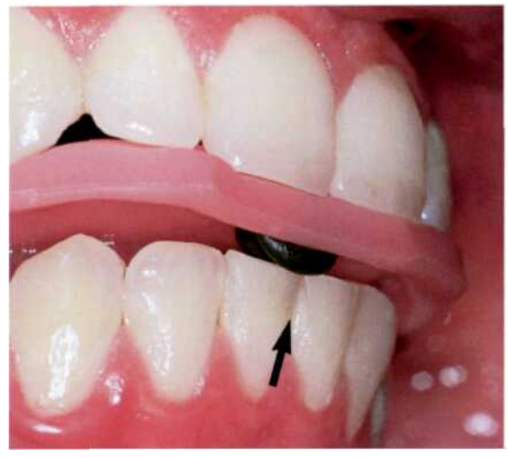
Right: The apparent stability of the position in the jig should not mislead one into overlooking the presence of a slight instability (red arrow).

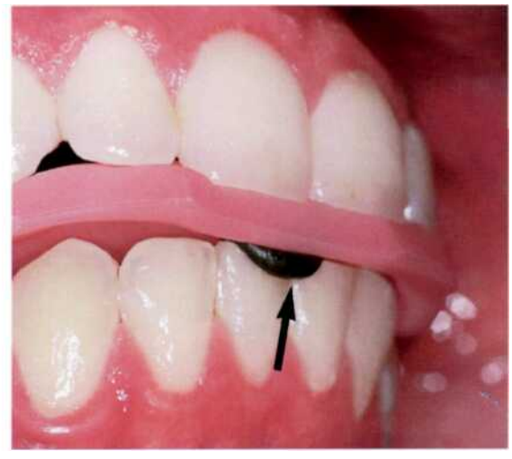




332 Reproducible stable position
Left: Mandibular position of a patient with good coordination just before the final closure into a jig of Kerr R compound. The incisors make no premature contact with any part of the jig, but repeatedly fit precisely into the anterior stop.

Right: There is no sliding movement in any direction as the lower incisors move from the position shown in the left photograph to their final position in the anterior jig. A reproducible stable position, from which one can proceed, has now been established.





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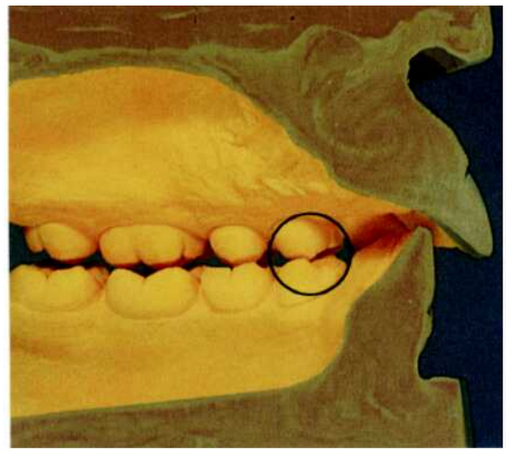
cle tone. The centric condylar position is identical with the *neuromuscular position* of the mandible and is located at the end of the muscle-guided closing movement (Brill and Tryde 1974).

The *unmanipulated mandibular position* usually lies anterior to the manually guided "centric." It can be reproducible within a range of 0.2 mm^2, and after preliminary splint therapy, within 0.1 mm^2 (Lotzmann 1994, Tripodakis et al. 1995).

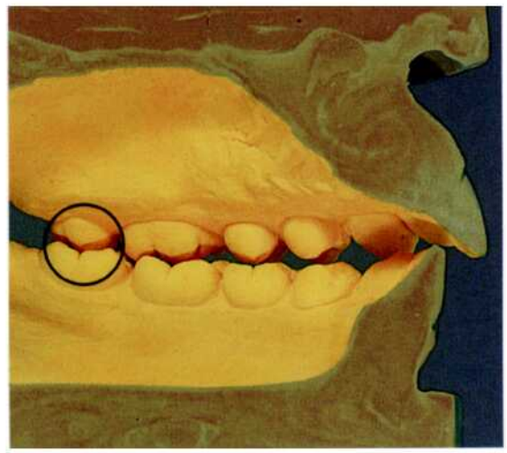
Manipulated mandibular positions are reproducible with an accuracy of 0.05-0.2 mm (Kantor et al. 1972, Piehslinger et al. 1993, Wood and Elliot 1994, Tarantola et al. 1997). As soon as the clinician's hands are removed from the mandible, however, it resumes its neuromuscular position.

This raises the question of how useful a reproducible manipulated position is for treatment. Furthermore, there is a daily variation of 0-4.02 mm in edentulous patients (Latta 1992, Utz et al. 1995) and 0.22-1.57 mm in dentate patients (Shafagh et al. 1975). Therefore we recommend the nonmanipulated neuromuscular mandibular position.



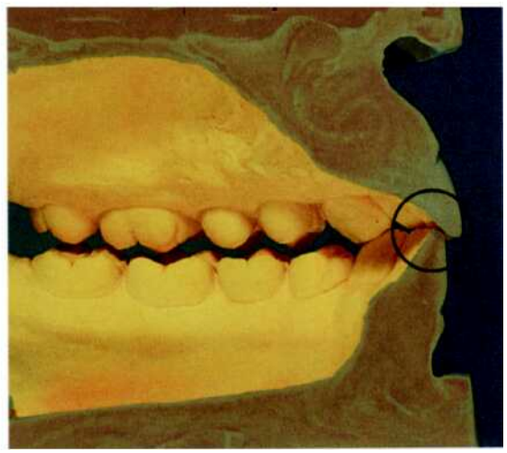
333 Posterior reference position
Left: Clinical procedure for registering a posterior reference position. The operator guides the mandible with the application of a retrusive force. While this does allow the establishment of a reproducible mandibular position, this position does not correspond to the neuromuscular relation.

Right: Typical occlusal relationship at the posterior reference position.



334 Anterosuperior reference position
Left: Clinical procedure for establishing an anterosuperior reference position. The condyles are manipulated over the pars intermedia of their disks against the articular eminences. This technique reduces the chance of an artificial posterior displacement, but always requires that there be a normal disk-condyle relation. This position is often different from the neuromuscular centric.

Right: Analogous representation of the occlusion under anterosuperior manipulation.



335 "Myocentric"
Left: With the body upright and the head held straight, the muscles of mastication are relaxed by rhythmic electrostimulation. From the resulting altered rest position the patient makes an effortless closure of 2 or 3 mm into the "myocentric" mandibular position. Myocentric usually lies anterior to the maximum intercuspation position, even in healthy subjects (Lotzmann 1999).

Right: Typical occlusal relation obtained using the Myomonitor.

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Static Occlusion

The objective of an examination of the static occlusion is to *determine any discrepancy between centric occlusion and habitual occlusion* (= static occlusal vector). Not every discrepancy is of equal importance to the treatment. Of primary interest are those occlusal vectors that are oriented in the same direction as the previously determined loading vector. That is because in these cases there is a direct correlation between the static occlusion and the loading vector, and it is reasonable to assume that this can be influenced by occlusal modifications.

Even if the preceding manual functional analysis detected no loading vector, the static occlusion should still be tested to eliminate any posterior occlusal vectors that might be present and that would load the bilaminar zone and have a possible negative impact on the disk-condyle relation.

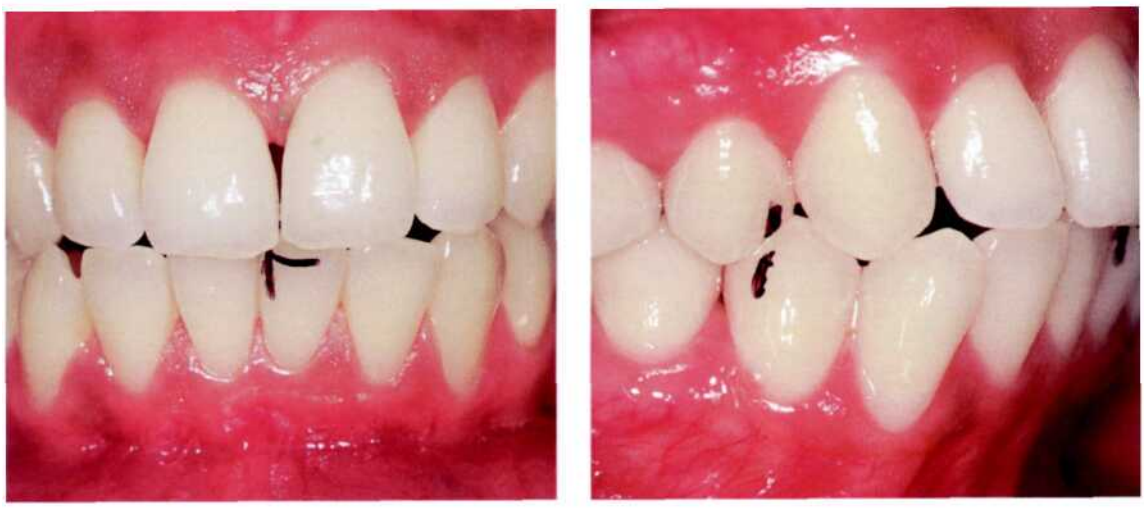
After reference lines have been drawn on the teeth in two planes and the neuromuscular system has been deprogrammed, the patient is asked to close to the first slight tooth contact with no manipulation by the examiner. Then,

336 Markings in habitual occlusion
Left: Before neuromuscular deprogramming the location of the midline of the maxillary dentition is transferred to the mandibular incisors. Using this same procedure the examiner can emphasize specific characteristics.

Right: Marking of the habitual occlusion in the sagittal plane. These markings are extremely helpful at first, but after gaining experience many clinicians omit them.

337 Centric occlusion
Left: Frontal view of centric occlusion after neuromuscular deprogramming by wide opening and closing movements that avoid tooth contact. The mandible deviates slightly to the right.

Right: Lateral view of centric occlusion after neuromuscular deprogramming. Here too a deviation from habitual occlusion (Fig. 336, right) can be seen.



338 Static occlusal vector
Left: Centric (above) and habitual (below) occlusion in a patient with a posterolaterally and superiorly directed loading vector in the right temporomandibular joint. From centric occlusion the mandible and the right condyle slide in the direction of the loading vector. Therefore, there is a connection here between the static occlusion and the loading vector.

Right: Palpating the condylar movement during the closing slide.

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from this centric occlusion the patient is instructed to slowly slide into habitual occlusion. The movement that results is monitored by observing the teeth and also by palpating the condylar regions. This is the quickest and simplest way to investigate the static occlusion.

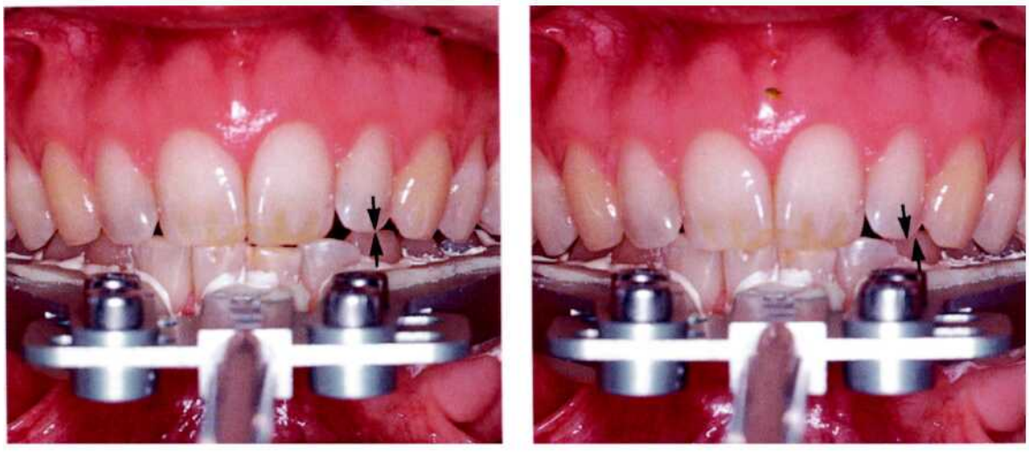
An alternative method is to make a registration in centric occlusion and centric condylar position for the *mounting of casts* in an articulator and then determine the static occlusal vector with a device for condylar position analysis (Fig. 339).

A further option for testing for the presence of a static occlusal vector is paraocclusal *electronic axiography* with correction for projection errors (Figs. 340 and 341). With this the occlusal vector can be displayed quantitatively on an electronic monitor.

The following can serve as a rough guide: If during the clinical testing no static occlusal vector can be demonstrated, there is no reason to mount casts (Fig. 339) or employ electronic axiography. If, on the other hand, a static occlusal vector is found to be present it can be specified, quantified, and documented for a planned treatment.

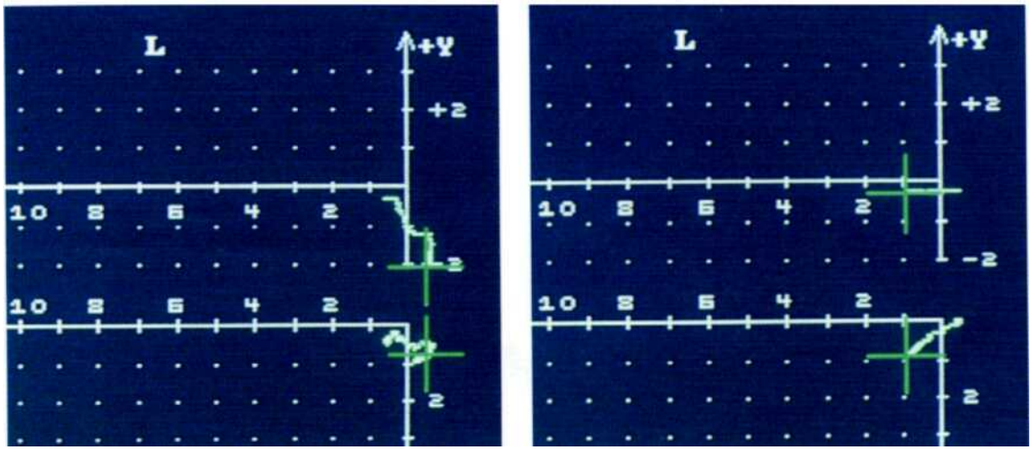
339 Mandibular position indicator (MPI)
Left To determine a static occlusal vector the casts are mounted in centric condylar position in an articulator. Then the upper member of the articulator is replaced with the MPI element.

Right: Because the MPI has no condylar housing, the maximum intercuspation of the cusps can be found and the discrepancy between this position and the centric mounting can be read from the measurement element.
Insert: red = centric, black = maximum intercuspation.



340 Electronic axiography
Left Paraocclusal axiography allows direct determination of how much the occlusion displaces the hinge axis. The condyles are displaced by approximately the same amount. The photograph shows the position of the mandible in centric occlusion.

Right Registration of the hinge axis displacement in habitual occlusion. The arrows make clear the shift of the mandible to the left from centric occlusion.



341 A sample axiogram for static occlusal vectors
In both cases the axiographic tracing begins at centric occlusion and ends in habitual occlusion (green crosses). With a presumed posterolateral loading vector, the occlusion in the left example would be increasing the stress (loading) on the lesion and in the right example it would be reducing the stress (unloading).

Left Example of a posterolateral occlusal vector.

Right Example of an anteroinferior occlusal vector.

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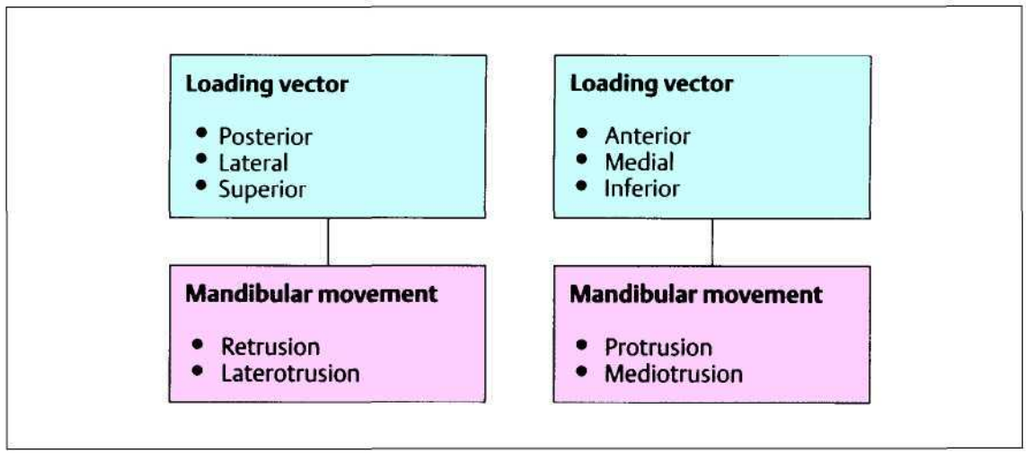
Dynamic Occlusion

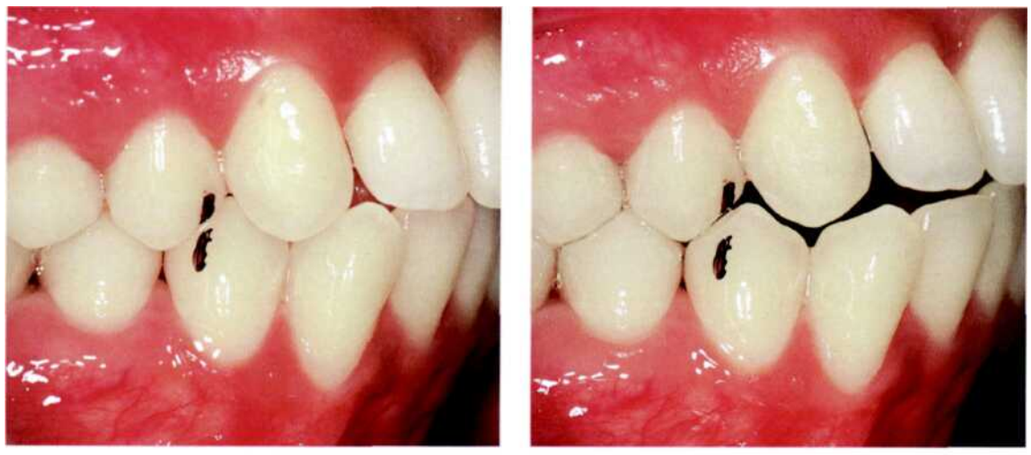
Dynamic occlusion is defined as the tooth contacts occurring during movement of the mandible. The objective of the examination of the dynamic occlusion is to detect any so-called dynamic occlusal vector—that is, any nonphysiological condylar movement that is imposed by the dynamic occlusion.

The dynamic occlusion can be tested during laterotrusion, mediotrusion, retrusion, and protrusion. To establish a causal relationship to a specific loading vector it is impractical to investigate all mandibular movements for every patient. Therefore before testing the dynamic occlusion the examiner calls to mind again the current loading vector. Its direction dictates which movements with tooth contact are to be studied (Fig. 342).

Thus there is no good reason to test a protrusive movement when there is a posterior loading vector because during protrusion the posterior portion of the joint is automatically unloaded and therefore, theoretically, a causal connection

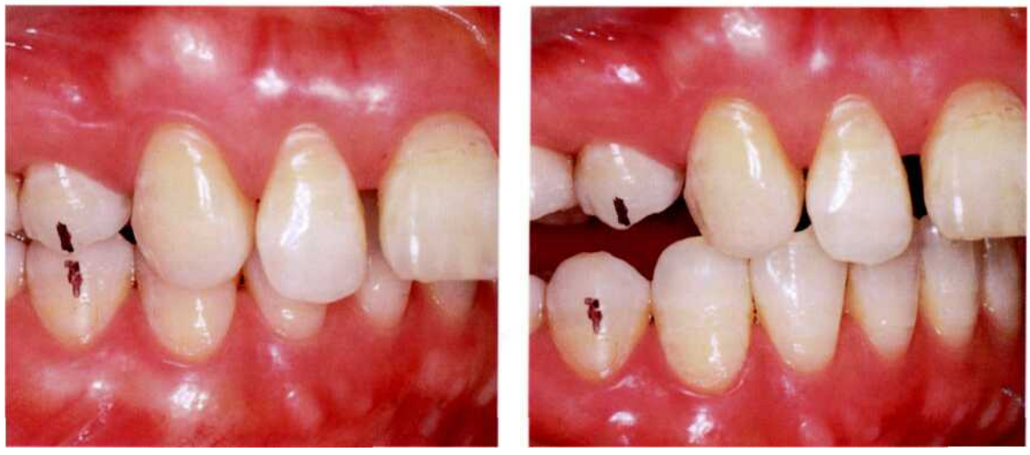


342 Loading vector and dynamic occlusion
The dynamic occlusion is tested only in those mandibular movements in which joint loading could occur in the direction of the loading vector. Therefore, the loading vector detected through manual functional analysis determines which dynamic occlusion must be investigated.



343 Physiological laterotrusive movement
Left: To test laterotrusion as part of an investigation of the dynamic occlusion, marks can be placed in the canine or premolar region.

Right The patient is asked to make a tooth-guided lateral excursion. In this case the mandible makes a clean movement to the right. During this movement the examiner monitors the condylar movement by palpation.



344 Laterotrusive movement
Left Marks have been made on the premolars in habitual occlusion. The patient has a posterolateral loading vector in the right temporomandibular joint.

Right As outlined in Figure 342, the next step is a test of the laterotrusive movement. A distinct lateroretrusion occurs rather than a simple lateral movement as seen in Figure 343. Here a causal relationship between the loading vector and the dynamic occlusion is apparent.

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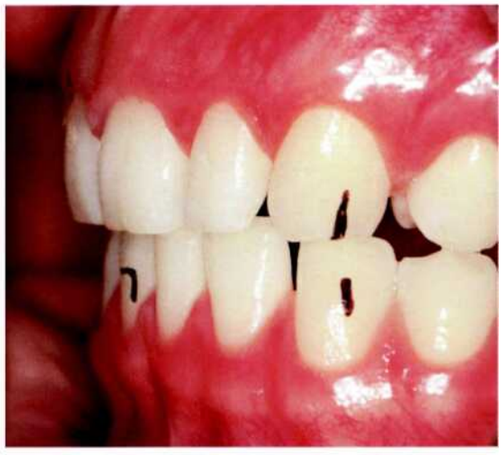
can already be excluded. Because posterolateral loading vectors occur most frequently, laterotrusion and retrusion are the elements of the dynamic occlusion that are regularly tested.

For this test the patient makes a lateral movement from habitual occlusion. During this movement there may be either a nearly pure rotation (no loading of the joint), a lateroprotrusion (relaxation of the bilaminar zone), or a lateroretrusion (loading of the bilaminar zone).

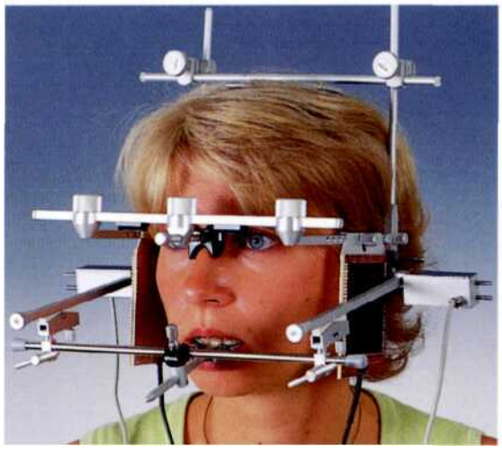
In a case with a posterolateral loading vector, the information from a lateroretrusion test could establish a causal connection between the loading vector and the dynamic occlusion. This can be determined either clinically or with electronic axiography.

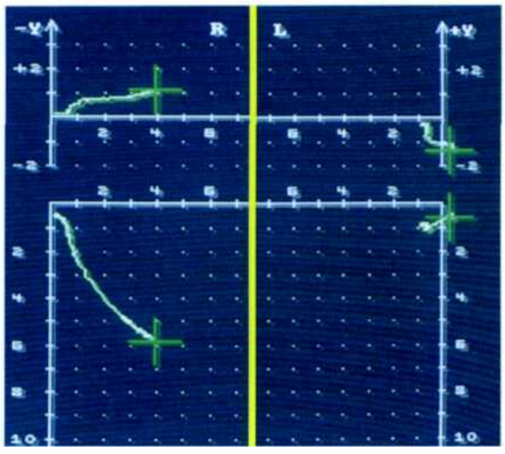
Before a treatment is recommended, the patient is asked to simulate a movement in the direction that will relax the joint. This movement will allow one to predict to what extent prosthodontic or orthodontic treatment can contribute to improvement of the dynamic occlusion.

345 Palpation of the condylar movement
The mandibular movements executed by the patient as part of the investigation of the dynamic occlusion are not only followed visually with the help of the marks made on the teeth, but their effects on the movements of the condyles are also monitored through palpation. Alternatively, this can also be accomplished through electronic axiography.



346 Occlusion during a simulated lateroprotrusive movement
Left: When a posterior or posterolateral dynamic occlusal vector has been demonstrated, the patient is always instructed to make a simulated lateroprotrusion. In this example, an unimpeded lateroprotrusive movement is prevented by contact of the lower canine against the posterior slope of the upper canine.
Right: In another case, the steep maxillary anteriors are interfering with a smooth laterotrusion. Orthodontic treatment will be required to reduce the dynamic occlusal vector in this patient.





347 Electronic axiography
Left: A dynamic occlusal vector can also be revealed by an electronic paraocclusal axiogram corrected for projection error. With this the examiner can observe a tracing of the condylar movement from habitual occlusion through laterotrusion. This is best seen in the horizontal plane.

Right: The axiographic tracing in the horizontal plane shows a distinct posterolateral movement of the left condyle. This movement can also be palpated clinically.

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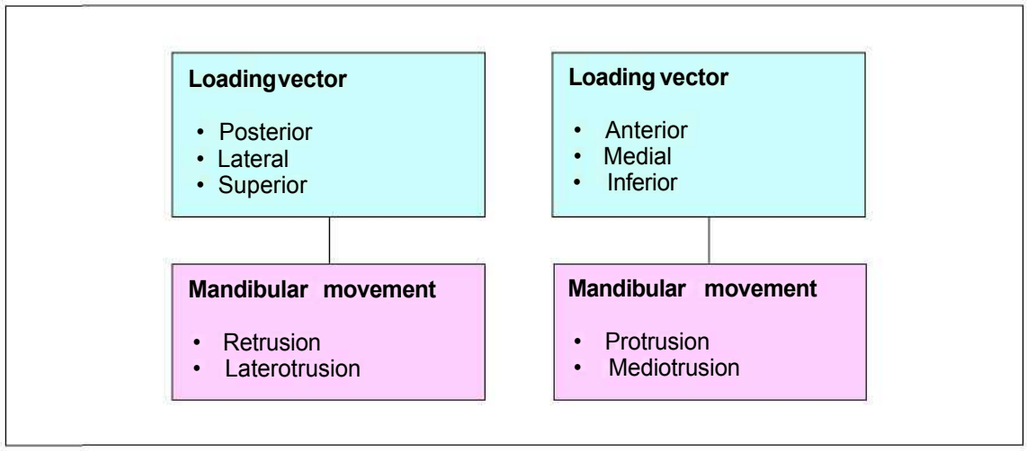
Bruxism Vector or Parafunction Vector

In the literature, connections between bruxism and temporomandibular joint disorders are frequently discussed (Rugh and Harlan 1988, Glares et al. 1998). Among clinicians the opinion is widespread that bruxism is precipitated, or at least aggravated, by premature occlusal contacts. This clinical observation has not yet been proven through controlled studies, however. It should be noted that an equilibrated occlusion permits an even greater level of muscle activity during tooth gnashing (Holmgren and Sheikholeslam 1994).

Bruxism in children is one aspect of personality development and usually ceases after a period of time. Presently there is no known connection between juvenile and adult bruxism (Kieser and Greoneveld 1998).

When a bruxism vector is detected, it is not the place of the dentist to conduct a psychological investigation into its cause. It is more important to identify the direction of the grinding activity and to clarify whether its direction corresponds to that of the previously diagnosed loading vector. This means that the examiner must contemplate theoretically which direction the patient would have to grind the

348 Loading vector and direction of bruxing
Before beginning the investigation for a bruxism vector the examiner must visualize the patient's loading vector. The mandibular movement that gave rise to the overloading can be deduced from this. With this in mind the examiner can pose the hypothesis: "If bruxism is causing the loading vector then there must be signs of bruxism in direction X." Then the hypothesis must be tested clinically.



349 Posterolateral loading vector on the right side
Left: Habitual occlusion of a 21-year-old female patient with a posterolateral loading vector on the right side. The presence of this loading vector calls for a study of the laterotrusive movement. The canine shows slight signs of abrasion.

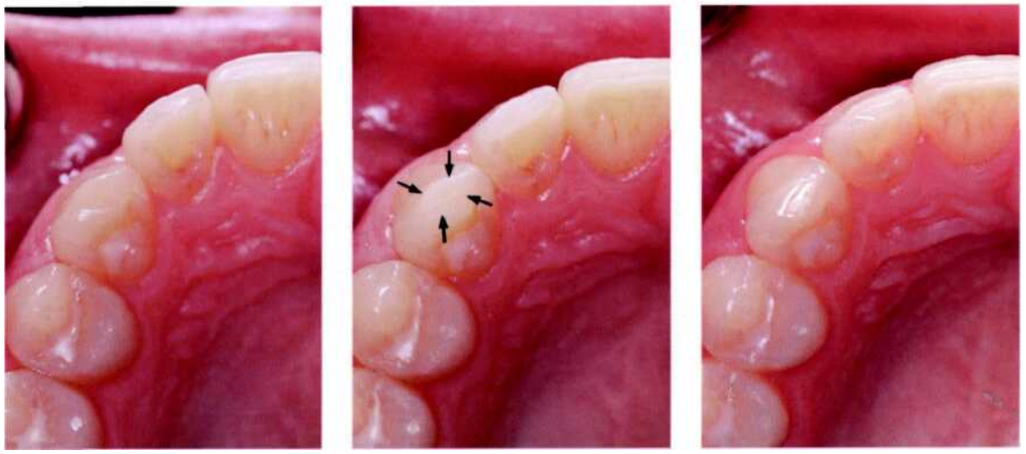
Right: Next the patient is asked to make a right lateral jaw movement as the examiner observes the direction in which the teeth move and palpates the movement of the condyles.

350 Differentiation between active and inactive facets
To test whether a facet is active or inactive, the facet can be given a matte surface.

Left: Facets in the mouth usually appear highly polished.

Center: By applying 10% maleicacid, a matte surface can be created as shown here on the canine (arrows).

Right: An abrasion facet that is active will appear highly polished again after 2 days.



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teeth to produce the present loading vector. Following that, the patient's teeth are examined for evidence of a corresponding bruxing activity. An accurate description of the bruxism direction provides answers to two important questions:

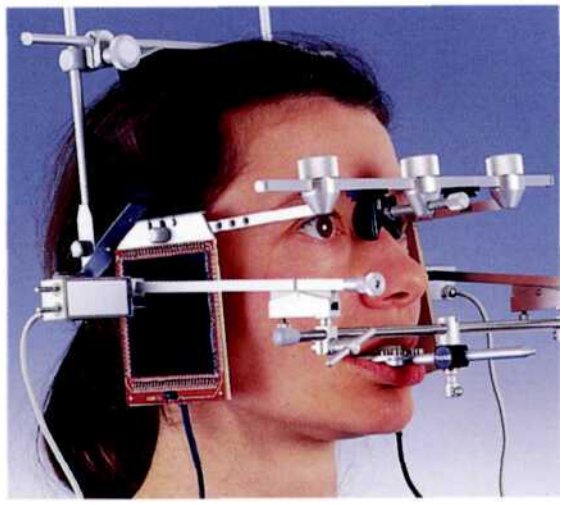
- Can occlusal treatment alone efficiently reduce a loading vector if there is no bruxism vector?
- Can a bruxism vector in the same direction be "turned around" by an appropriately shaped splint?

As has been demonstrated, splint therapy does not end bruxing activity (Holmgren et al. 1993, Yap 1998). Nevertheless, a splint can provide symptomatic relief by reducing the frequency and duration of the grinding phases (Pierce and Gale 1988). Biofeedback and relaxation exercises during the day do not produce this effect. As soon as use of the splint is discontinued, however, the original frequency and intensity of grinding are resumed (Hersek et al. 1998). The occlusal design of the splint (canine guidance and/or molar guidance) likewise has no significant effect on the muscle activity (Rugh et al. 1989). A cause-oriented, long-term treatment of bruxism includes the changing of the pattern of emotional stress resolution (Rugh and Harlan 1988). All that a splint can do is reduce the loss of tooth structure and, in some cases, change the direction of the bruxism vector.

351 "Key-and-lock" principle with an anterior bruxism vector
Left: Laterotrusive position (dynamic occlusion) of the patient in Figure 349.

Right: To make the teeth fit exactly in the key-and-lock position, the mandible must be moved forward. The resulting anterior bruxing vector has no causal connection with the loading vector, because in this patient the bruxing vector is directed posterolaterally. In this example the dynamic occlusion *(left)* is responsible for the loading vector.

352 "Key-and-lock" principle with a posterior bruxing vector
Left: Laterotrusive position (dynamic occlusion) of a 19-year-old female patient with a posterolateral loading vector. Notice the separation between the maxillary first premolar and the mandibular canine (arrows).
Right: Key-and-lock position in the same patient. As the patient searches for the bruxism facet, the mandible and its right condyle moves posterolaterally in the same direction as the loading vector. This indicates that in this patient the bruxism contributes to the loading vector.



353 Diagnostic procedure for a bruxism vector
Left: A bruxism vector can be diagnosed clinically through observation of the relative tooth positions with simultaneous palpation of the movement of the condyles. This method is quick and inexpensive, but requires experience.

Right: The second method utilizes electronic paraocclusal axiography. Mechanical axiography systems are not suited to this purpose because of projection errors.

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Dysfunctional Movements

The same basis principles that were used to investigate etiological factors are followed to verify that dysfunctional movements are contributing to the existing loading vector. First the examiner must visualize again the specific loading vector. Next he/she must look for any obvious dysfunctions that are aligned in the exact same direction. This search can lead from lip and fingernail biting, through the sleeping position, and on to specific patterns of movement while playing certain musical instruments. Because the number of possible dysfunctions is limitless, in many cases the only course left is to explain in detail the direction of the malfunction and ask the patient to look for possible causes in his or her daily activities. At the same time, the patient is instructed to load the joint as little as possible in the direction of the loading vector. Some disturbed movement patterns may be related to static or dynamic occlusal factors (Nishigawa et al. 1997). Dysfunctions of the tongue undoubtedly have an important influence on the position of the teeth in the jaws, but their role in temporomandibular joint disorders is only secondary.

354 Outline of dysfunctional movements

The lips, cheeks, and tongue are frequently involved in dysfunction or dyskinesia of the masticatory system (Clark et al. 1993b). Thumb or finger sucking has an especially deleterious effect on the alveolar process and the tongue (van Norman 1997). Increased muscular activity of the tongue is associated with increased activity of the temporal and suprahyoid muscles. The activity of the masseters, on the other hand, is largely independent of tongue function (Carlson et al. 1997).

Dysfunction of the	lips	cheeks	tongue
Type of dysfunctional movement	• Lip pressure • Lip sucking • Lip biting • Lip rubbing	• Cheek pressure • Cheek sucking • Cheek biting • Cheek rubbing	• Tongue pressure • Tongue biting • Tongue rubbing • Swallowing pattern • Thumb sucking • "Playing with the tongue"
Dentoalveolar effects	Probable	Probable	Probable
Loading vector for the TMJ	Possible indirectly	Possible indirectly	Seldom a cause

355 Habits

A wide range of habits are known to be of clinical significance. These include nail biting, improper posture while telephoning, and certain sleeping positions.

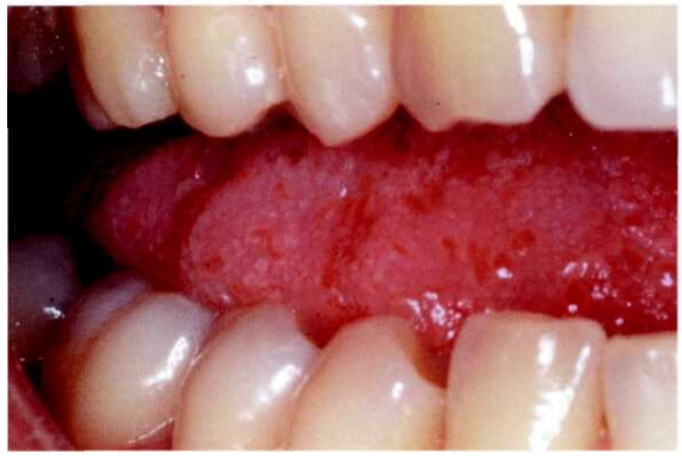
The patient shown here used to play excessively with thread. Although this had no effect on the joints, the effect on the teeth is striking.

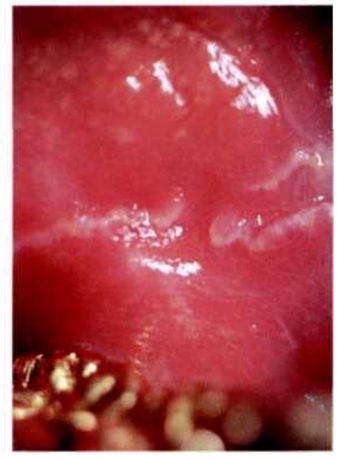
Right: Facial view in maximal occlusion showing the damage to the dentition.

356 Imprints in the tongue and cheeks

Hyperactivity of the tongue has frequently been mentioned in connection with functional disturbances of the temporomandibular joints. Hyperactivity can be easily deduced from the tooth imprints in the border of the tongue *(left)*. While it is true that the tongue has been demonstrated to have harmful effects on the alveolar processes, it is only rarely associated with dysfunctional loading of the temporomandibular joints.

Right: Habitual buccinator pressure with chronic cheek biting.





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Influence of Orthopedic Disorders on the Masticatory System

In addition to the current loading vector and stresses arising within the masticatory system, there are still a number of other potential etiological factors. Certainly, orthopedic problems play a special role here (Rocabado 1983, Kirveskari et al. 1988, Solow and Siersbaek-Nielsen 1992, Smith 1993, Huggare and Houghton 1996) as do osteopathic conditions (Magoun 1975, 1979, Gillespie 1985, Paul and Buser 1996). Aside from the discussion about the connections between general joint hypermobility and temporomandibular joint disorders (Perrini et al. 1997), the greatest question in dealing with functional disturbances in the masticatory system is whether we are facing a so-called descending or ascending problem (Serviere 1989, Schöttl 1991). With a *descending problem* the disturbance begins primarily within the joint, while in an *ascending problem* the functional disorders in the masticatory system are the result of another disorder outside the joint. There are many different opinions on this topic, but no controlled studies. Recent investigations (Bumann et al. 1999) indicate, however, that significantly more problems are ascending than descending, especially among chronic pain patients.

357 Anterior positioning of the head
With this head posture there is an unfavorable position of the cervical spine. Increased tension in the suprahyoid muscles gives rise to a posterior loading of the temporomandibular joints. However, the passive compression tests in this direction will be positive only if the bilaminar zone has little capacity for adaptation. This variation in adaptability is also the reason that identical orthopedic findings in different patients are sometimes accompanied by symptoms and in other cases not.

358 Torticollis (wryneck)
Eighty percent of cases of torticollis in children and adolescents have a muscular etiology. Of the remaining 20%, one third have Klippel-Feil syndrome and two thirds represent neurological disturbances. The neurological disturbances are further divided into ocular disorders and disturbances of the brachial plexus and the central nervous system (Caputo et al. 1992, Feiler and Craig 1993, Ballock and Song 1996). Torticollis usually produces a posterosuperior loading in the temporomandibular joint on the same side.

359 Rotation of the head
Example of an extreme anterior positioning of the head. Upon dorsal inspection it is apparent that there is also lateral flexion to the left and rotation to the right. In combination with the unilateral protrusion of the left shoulder there is a posteromedial loading of the right temporomandibular joint. If a loading vector can be demonstrated in this direction, treatment of the temporomandibular joint will have to be interdisciplinary.

Left: Lateral view.

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Supplemental Diagnostic Procedures

Only a part of all the factors acting upon the masticatory system can be adequately investigated in the dental office. The objective of the procedures included under manual functional analysis is the identification of so-called static and dynamic occlusal vectors, bruxism vectors, and dysfunction or dyskinesia vectors (pp. 124ff.).

If the examiner is also competent in disciplines other than dentistry (such as osteopathy, orthopedics, neurology, kinesiology, or acupuncture), he/she may explore other etiological factors. It is not enough, however, to only gather findings in one particular field. One must also verify that the diagnosed disorders contribute to the known loading vector in the masticatory system.

If, for example, a patient has a capsulitis with posterior loading vector in the right temporomandibular joint and also has a pelvic tilt, interdisciplinary treatment is not necessary unless there is proof that correction of the pelvic tilt will lead to an anterior repositioning of the affected condyle. But this is the case with only a portion of the patients!

360 Supplemental diagnostic procedures
In addition to the examination methods described previously, a number of directly complementary diagnostic methods are available to the clinician. Furthermore, it is recommended that the practitioner make use of the competence of a professional colleague who is well versed in this area.
The advantages and disadvantages of these supplemental methods are discussed thoroughly in the text.

Supplementary diagnostic measures

D MRI	D Lateral ceph	D Analysis of etiological factors	D _____
D CT	Q Articulator adjustment	Q Joint vibration analysis	D _____
D Panoramic X-ray	D Instrumental occlusal analysis	D Osteopathic examination	

Thus identification of a loading vector makes it possible to establish a causal relationship between nonadapted structures and potential etiological factors. Therefore the loading vector stands at the center of manual functional analysis.

Mounted Casts, Axiography

As mentioned in earlier sections of this book, a loading vector can be determined only through systematic use of manual examination techniques. The same is not true, however, for *investigating the local etiological factors—static* occlusion, dynamic occlusion, bruxism, and dysfunctions—for which instrumented analysis can also be helpful. A discrepancy between centric and habitual occlusion can be determined not only clinically, but also with the aid of mounted casts (pp. 201 ff), a Mandibular Position Indicator (MPI, p. 246), or through paraocclusal electronic axiography corrected for projection errors (p. 264).

While *mechanical axiography* is suitable for programming the condylar path inclinations and setting the Bennert angle on an articulator (p. 263), it cannot provide any reliable information for the evaluation of etiological factors because of the inherent projection errors (p. 261). In fact, neither the mechanical nor the electronic axiogram is indicated for differentiating clicking sounds in the temporomandibular joint. While the domain of mechanical axiography is programming of the articulator, the primary field of application of *electronic axiography* is the specific examination and documentation of influences of the dynamic occlusion, bruxism, and individual dysfunctions upon the joints. An indication for electronic axiography exists only if clinical investigation of the corresponding etiological factors has provided evidence of a vector. As part of the paraocclusal axiographic registration, note should be made of any discrepancy in the static occlusion between centric occlusion and habitual occlusion. Discrepancies between habitual occlusion and the dynamic occlusal position, bruxism position, and dysfunction position are noted during the evaluation of dynamic occlusion, bruxism, and dysfunctional movements. Their graphic representation (= vector) allows simple comparison with the individual loading vectors of the patient so that a causal connection can be either verified or excluded.

Regardless of the instrument used, tracings of active mandibular movements are so nonspecific that one should not make a differential diagnosis and treatment plan from their registration or from an attempted interpretation of the pathways (Lund et al. 1995). Nevertheless, these systems can be useful in the scientific investigation of certain theoretical questions.

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Panoramic Radiograph

The panoramic radiograph serves mainly to rule out primary joint diseases (see also pp. 142ff.). Under certain conditions it can reveal periapical inflammatory processes or various other intraosseous changes that could be considered as sources of pain in making a differential diagnosis. Fractures, tumors, osteomyelitis, and ankylosis should be ruled out. Hyperplasia of the coronoid process can be identified in the panoramic radiograph. Ossification of the stylohyoid ligament can likewise be clearly visible, although no conclusions regarding the presence or absence of clinical symptoms can be made from this finding. The panoramic radiograph is not suitable for evaluating the condylar position or measuring the joint space. Nor can apparent asymmetry of the ascending rami of the mandible seen on a panoramic radiograph be reliably evaluated as a pathological condition in urgent need of treatment (Türp et al. 1995, 1996,1998).

Caution is also advised in evaluating degenerative bone changes in the condyle: Because of the adaptability of the cartilaginous joint surfaces, degenerative changes in the joints may be covered by a layer of radiolucent fibrocartilage. This can allow the joint to function "normally" even though the radiographic image shows something quite different. Finally, the clinical findings (see p. 68f) always take precedence over the radiographic findings.

Tissue-specific primary diagnoses (decompensated functional disturbances)	**Loading vector**	**Stat. occl.**	**Dyn. occl.**	**Bruxism**	**Dysfunction**
1.					
2.					
3.					
4.					
Tissue-specific secondary diagnoses (compensated functional disturbances)	**Loading vector**	**Stat. occl.**	**Dyn. occl.**	**Bruxism**	**Dysfunction**
1.					
2.					
3.					
4.					

Possible effect on the choice of supplemental diagnostic measures

• Imaging procedures • Medical laboratory studies (e.g. rheumatoid arthritis) • Referral to other disciplines	No influence on the choice of supplemental diagnostics	• Mounted casts • Paraocclusal electronic axiography • Lateral jaw radiograph	• Paraocclusal electronic axiography

361 Supplemental diagnostic measures and the foundation of the tissue-specific diagnosis

The tissue-specific diagnosis arrived at through a clinical examination can, in individual cases, be confirmed by imaging procedures. While the panoramic radiograph is used more for excluding alternative diagnoses, sometimes MRI or CT can be useful as a supplemental diagnostic procedure.

In addition, systemic diseases suggested by clinical evidence should be either confirmed or ruled out. If occlusal vectors are present, they can be documented and their magnitude estimated with the aid of mounted casts, lateral jaw radiographs, and electronic axiography. Vectors of bruxism and dysfunctions, on the other hand, can be quantified only through clinical or axiographic procedures. Mounted casts and radiographs provide no additional help in these cases.

The so-called functional panoramic radiographs provide no additional information that would significantly affect the diagnosis or treatment. From a therapeutic viewpoint, these additional procedures are unnecessary.

Lateral Jaw Radiograph

A lateral jaw radiograph may be necessary in preparation for treatment to reposition an antertiorly displaced disk. It provides much useful information including compensatory tooth positions and especially the size of the gonion angle, the mandibular plane angle and the posterior facial height (p. 151).

Joint Vibration Analysis (JVA)

Joint vibration analysis (Ishigaki et al. 1993) can be helpful in the documentation of joint clicking sounds, but at present it provides no information for a dependable differential diagnosis.

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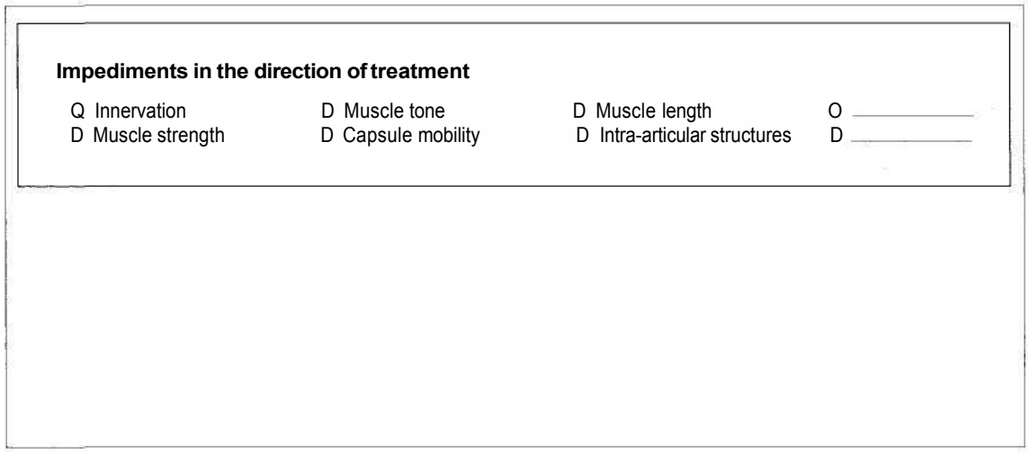
Musculoskeletal Impediments in the Direction of Treatment

In the first part of manual functional analysis the loading vector is determined, and in the second part the various etiological factors are investigated. Before treatment is actually begun, any possible musculoskeletal impediments in the direction of treatment must be identified. The *direction of treatment* has already been predetermined by the loading vector (p. 55): it is always *directly opposed to the loading vector.*

If the loading vector is produced by disturbances of the static or dynamic occlusion, there is a strong possibility that the existing symptoms can be aleviated through occlusal treatment. The relief of occlusal disturbances is always accompanied by alteration of the current (habitual) condylar position. Successful repositioning of the condyles into the centric condylar position depends upon the innervation, tonus of the neuromuscular system or of individual antagonistic muscle pairs, the length of the musulature, muscle strength, joint capsule mobility, and the positional relationship of the intra-articular structures such as a nonreducing disk displacement. In some cases, each of these potential musculoskeletal impediments in the masticatory system

362 Section from the examination form for recording the impediments in the direction of treatment
The physical therapist is qualified to eliminate skeletal impediments. Therefore an interdisciplinary approach to treatment is always indicated when one or more boxes in this section are checked and the condylar position is to be therapeutically altered. If dental treatment is to be performed without changing the condylar position, this part of the examination may be omitted.



can be decisive in determining whether or not it is possible to reposition the condyles in the direction of treatment.

A basic rule is: The greater the number of impediments and the more pronounced the individual symptoms, the more difficult will be the attempt to achieve neuromuscular repositioning of the condyles in the direction of treatment. Clarification of the impediments therefore makes it possible to answer the following questions:

- Is it possible at all to bring about a neuromuscular change in the condylar position?
- If so, will the repositioning be simple (= no impediments) or very difficult (= multiple impediments that can be overcome through interdisciplinary treatment)?

Conversely, the implication of this for clinical diagnostics is that with patients for whom a change in condylar position is neither necessary nor planned, an investigation of the musculoskeletal impediments would be superfluous.

The removal of musculoskeletal impediments to simplify a neuromuscular change of the condylar position is primarily the responsibility of the physical therapist as a member of the interdisciplinary treatment team. The primary goal in the treatment of impediments is their elimination, but just as important is *preservation of the regained mobility by a corresponding modification of functions,* such as posture, locomotion, chewing, swallowing, and speech. This second aspect is decisive for the long-term success of treatment, but is frequently neglected or under-appreciated by clinicians.

The clinical examination for possible impediments represents one more unavoidable investment of time after most of the signs and symptoms have already been gathered during the previously described examination procedures and recorded in the manual functional analysis form.

Disturbances of innervation of the lateral pterygoid muscle, as for example following a stroke or neurosurgery, are seldom encountered in a dental practice. These can be diagnosed relatively easily through isometric contractions. If the active movement is limited but not the passive movement, and if during isometric contraction the corresponding muscle has absolutely no strength, then a disturbance of innervation is present. Immediately after making this diagnosis, a referral to a neurologist should be made, especially if there was no specific event in the patient history to account for the condition. All the physical therapist can do in the way of treatment is to provide training for the weakened muscles to compensate for the disrupted innervation. In some cases, this can be quite effective.

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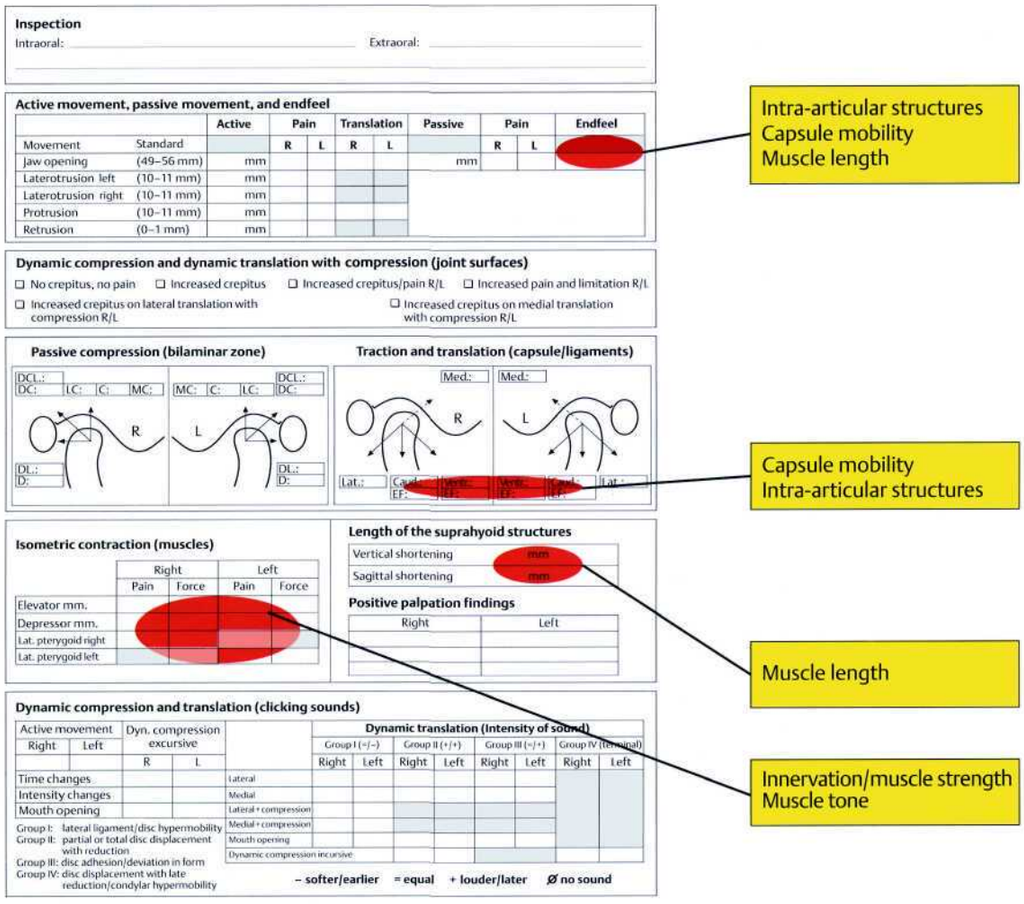
Muscle tone can only be evaluated by observing muscle activity throughout the entire examination and by palpating the muscles in question. For a hypertonic musculature the tonus can be reduced by the physical therapist through special relaxation techniques (Gramling et al. 1996, Dworking 1997) and by the patient through biofeedback and self-administered training (Greco et al. 1997, Snaith 1998). If these exercises are not kept up consistently, success of the treatment is often only temporary.

The *muscle length* of the elevators can be determined by the endfeel of passive jaw opening. An endfeel that is too soft and limitation of opening (about 38-44 mm) are the diagnostic criteria of *muscle shortening of the elevators* (Bumann and Groot Landeweer 1992, Visser et al. 1995, Hesse et al. 1996). The physical therapist mobilizes shortened muscles through dynamic and static muscle stretching (Bandy et al. 1998). The *length of the suprahyoid musculature* is tested by extension of the cervical spine with the teeth held in an end-to-end relationship (see p. 96). This is especially useful in the treatment of patients with skeletal mandibular retrusion and patients receiving orthodontic treatment combined with orthognathic surgery. These muscles can be therapeutically stretched through extension exercises, origin-insertion stretching, and lateral mobilization of the hyoid bone.



363 Possible diagnoses of musculoskeletal impediments
Overview of the clinical examination techniques used for diagnosing musculoskeletal impediments in the direction of treatment. Shortening of muscles and reduced capsule mobility are the most important obstructions for the dental practitioner. As in all precision techniques in dentistry, before one can make a reliable evaluation of the endfeel it is necessary to receive appropriate instruction and to proceed in an orderly manner. Although the subjective determination of the endfeel is sometimes viewed with reservation in scientific studies, for the clinician there is no better diagnostic tool. In our experience, the failure to consider the impediments in the direction of treatment is a frequent cause of unsuccessful treatment and return of the distressful symptoms.

A test of *muscle strength* as it relates to positioning of the condyles is especially important for the lateral pterygoid muscles and is accomplished by isometric contractions. The weaker these muscle, the more difficult it is for the condyles to assume an anterosuperior position. The physical therapist can relieve this condition through isometric and isotonic exercises.

Reduced joint capsule mobility is the most common and most clinically relevant impediment in the direction of treatment. It is diagnosed by determining the endfeels of anterior translation and inferior traction (see p. 75) An endfeel that is too hard indicates a constriction of the capsule or functional joint compression (Bumann et al. 1993). Systematic traction and translation exercises by the physical therapist and insertion of a decompression splint by the dentist are recommended.

Derangements of intra-articular structures (e.g. disk displacements with or without repositioning) can also present an impediment in the direction of treatment. If the joint is painless and well adapted, its mobility can be improved through traction and translation.

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Manual Functional Analysis for Patients with no History of Symptoms

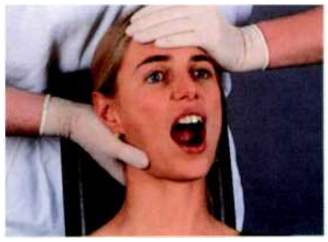
The typical patient population in a dental practice is made up of patients whose joints are healthy (fully adapted) and those with compensated or decompensated functional disorders. Patients with compensated disorders give no history of symptoms; however, reproducible symptoms can be provoked under specific loads. Because the case histories cannot distinguish these patients from healthy ones, *every* patient must receive a functional examination before receiving dental treatment. This is especially important prior to orthodontic treatment because the forces necessary for tooth movement place additional stress on the system, and in some cases this can tip the balance toward decompensation.

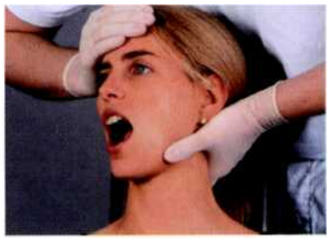
The goal of the examination is the differentiation of compensated and decompensated functional disturbances. To this end, tests are conducted to detect the presence of:
- loading vectors
- restrictions to movement
- occlusal vectors (see pp. 126ff.).

364 Overview of the various techniques used during a routine examination

Passive jaw opening

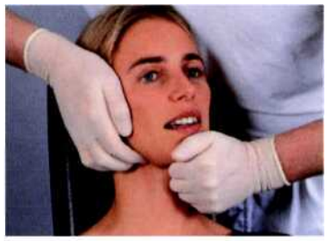
Dynamic (passive) compression

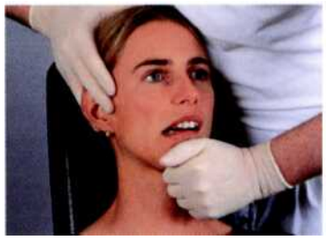

Lateral dynamic translation

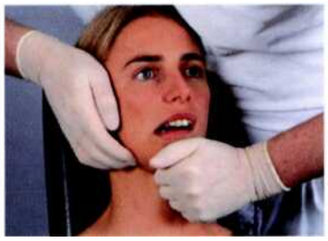

Medial dynamic translation

Superior compression

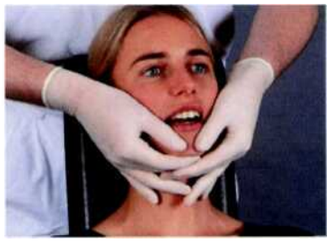
Posterior compression

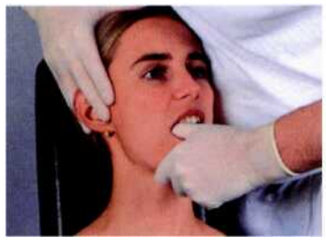

Posterosuperior compression

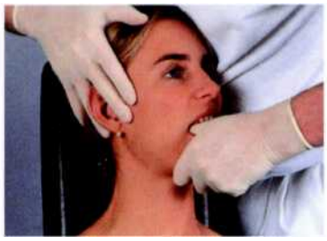

Posterolateral compression


Posterosuperior compression

Isometric contraction of the closing muscles


Isometric contraction of the opening muscles


Anterior translation


Traction

Length of the...

... suprahyoid structures

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Imaging Procedures

Imaging procedures are almost never useful as primary tools for diagnosing functional disturbances. While they do provide some information about the form and position of structures, only a very few techniques can disclose any information about function. The occurrence of symptoms depends primarily upon function and the capacity for adaptation. In this regard, one must give special attention to the functional adaptability of the nonbony structural components of the joint. With the exception of MRI, imaging procedures cannot reveal evidence of adaptation in the bilaminar zone, the fibrocartilaginous articular surfaces, or the disk.

In the field of dentistry today there are two *general indications* for the use of imaging procedures: exclusion of primary diseases of the joint and visualization and documentation of adaptations. These requirements are usually satisfied by the MRI, panoramic radiograph, or long-cone extraoral radiograph.

There are a wide variety of techniques available for making images of the temporomandibular joint (Christiansen and Thompson 1990, Westesson and Katzberg 1991, Katzberg and Westesson 1993, Heffez 1995, McCain 1996). The reasons for such a large number of techniques are:

- The fossa and the condyle exhibit great biological variations.
- Techniques that reproduce bone structure well are frequently poorly suited for imaging soft tissues, and vice versa.
- Images of nearby bony structures can be superimposed to varying degrees on those of the joints.
- The alignment of the condyle in three-dimensional space can lead to a distorted picture of its relationship to the fossa, thus the angle of the radiation beam must sometimes be individualized.

Examination of the temporomandibular joint through imaging procedures is further complicated by the combination of medical and legal considerations, plus an incomplete understanding of exactly what diagnostic procedures are relevant to treatment planning. From a purely medical standpoint, the indications for imaging procedures are simply to separate primary joint diseases from functional problems, to identify adaptations, and to describe the positional relationships between disk and condyle.

All other indications are of a mostly legal nature and their value should be carefully weighed against the added radiation exposure they entail.

It is a long-recognized and undisputed fact that tomograms, for example, allow bone of the condyle and the temporal portions of the joint to be viewed in better detail. What is frequently overlooked, however, is that the detailed changes seen have no affect on the treatment. The section on testing of the joint surfaces (p. 68f) thoroughly explains how almost all functional problems of the joint surfaces can be diagnosed clinically. If detailed imaging shows a deviation from normal but there are no symptoms, no treatment is indicated. If there are clinical symptoms of a joint surface problem and the radiological findings confirm this, still the radiographs will have no influence on the treatment. For these reasons, one should be extremely reluctant to declare the need for transcranial eccentric radiographs, tomograms, transmaxillary and transpharyngeal radiographs, or so-called temporomandibular joint programs with panoramic machines.

This chapter contains information about the different imaging procedures, their advantages and disadvantages as well as their indications. The section on MRI is discussed more thoroughly, as this procedure is assuming a growing role in the diagnosis of temporomandibular joint disorders. Nevertheless, practical articles on this theme appearing in the literature are frequently all too brief.

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Panoramic Radiographs

Panoramic radiograph machines have become quite common in dental offices (Friedland 1998, Whaites and Brown 1998) and the radiographs made with them are offered as a routine procedure.

Modern machines deliver a radiation dose of approximately 20 mGy (milligrays; 1 gray = 100 rad) to the skin's surface (Goldstein 1998). The dose to the salivary glands varies from 0.7 to 4.17 mGy, and the thyroid gland receives 0.03-0.370 mGy (Nilsson et al. 1985, Underhill et al. 1988). With digital equipment (McDavid et al. 1995) the exposure can be reduced by about 43% with no loss of quality in the detection of radiolucent abnormalities (Dula et al. 1998).

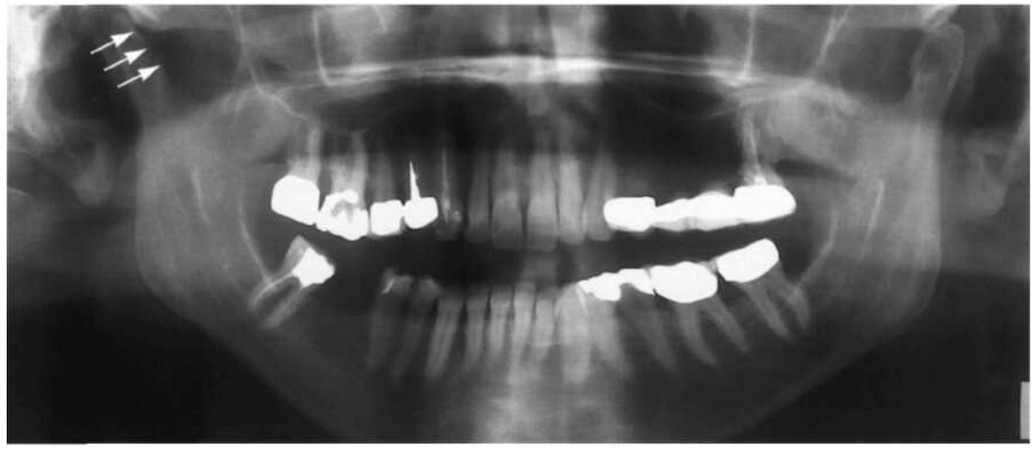
An accurate *evaluation of carious lesions* is possible only to a limited extent. The combination of a panoramic radiograph with bite-wing radiographs, however, does provide reliable caries detection and does not necessarily require additional periapical films (Richardson 1997, Flint 1998).

A panoramic radiograph has a magnification factor of 7-27% (Updegrave 1966, Manson-Hing 1971, Akesson et al. 1992).

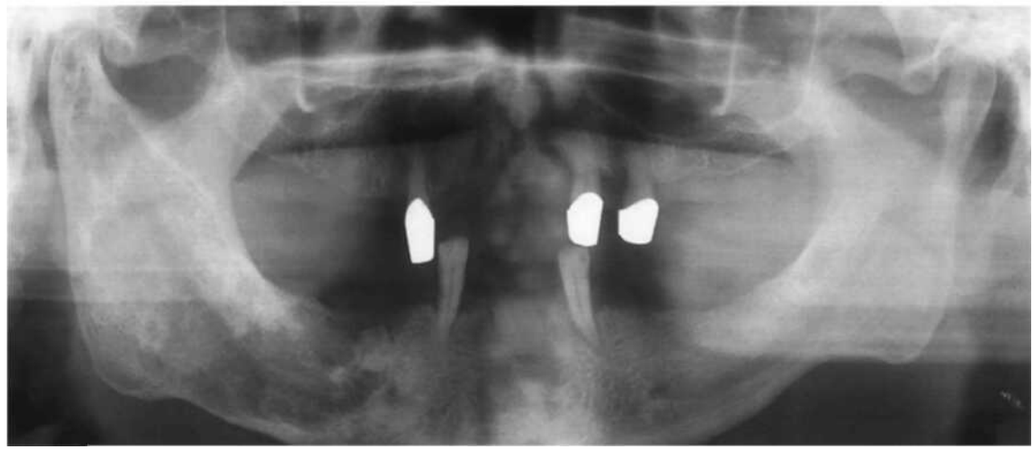
365 Physiological joints
As part of the functional diagnostics the panoramic radiograph is the method of choice for
- Confirmation of presumed degenerative bone changes.
- Diagnosis of unsuspected pathology.
- Classification of the stage of a disease process.
- Evaluation of the effectiveness of therapeutic measures (Kaplan 1991).

The condyles can be evaluated well provided the radiograph was not made with the teeth in habitual occlusion.

366 Degenerative changes in the right joint
The most common finding in a degenerating temporomandibular joint is a change (regressive adaptation) of the condylar bone that is accompanied by a more or less pronounced flattening of the contour (arrows). In spite of the altered bony structure, the fibrocartilaginous joint surface may be completely adapted. In that case the joint is functionally intact and in no need of treatment. If the joint surfaces are not well adapted there will be a clinically detectable crepitus.



367 Osteomyelitis in the mandible and in the right temporomandibular joint
Osteomyelitis in the mandible extending all the way to the condyle can mimic the clinical symptoms of a temporomandibular joint problem. The symptoms, however, cannot be reproduced by the joint-play test. In the radiograph the trabecular structure has a looser, more "cloudy" appearance on the right side than on the left. Osteomyelitis of the mandible is frequently accompanied by anesthesia of the lower lip. The differential diagnosis must rule out a metastasis (Glaser et al. 1997).



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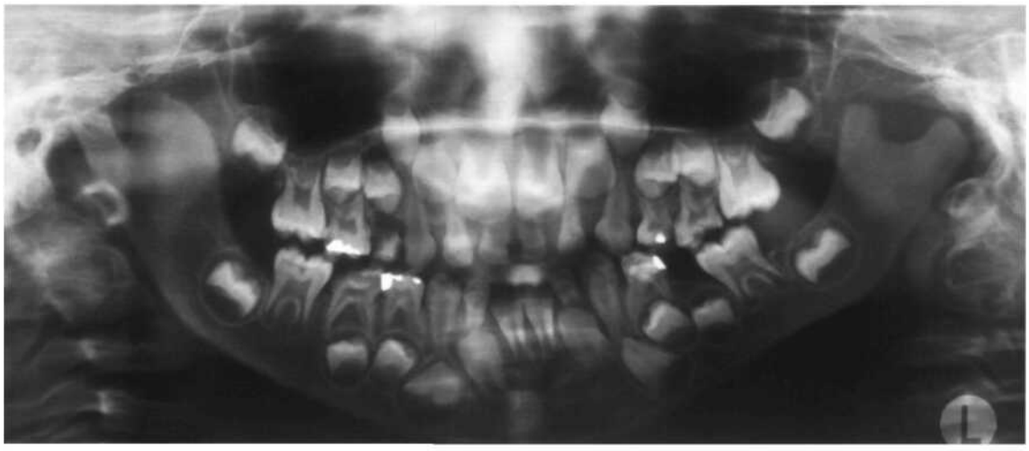
The panoramic radiograph of the temporomandibular joint serves only to reveal *advanced degenerative changes of the condyle and primary joint problems* such as fractures, joint involvements with syndromes, tumors, cysts, osteomyelitis, hyperplasias, hypoplasias, and aplasias (Dixon 1995, Wilson 1996, Greenan 1997, DelBalso 1998). Considering these indications, the panoramic radiograph is the only radiograph necessary for many patients (Brooks et al. 1997).

To minimize superimposed images of the condyle and bony fossa, the exposure should not be made with the teeth in habitual occlusion. Firm judgements about bony changes in the condyle can be made only for those occurring in the lateral and central portions (Hollender 1994).

Findings from panoramic radiographs agree with those from tomograms in 60-70% of joints (Bezuur et al. 1989, Ludlow et al. 1995). In many cases, however, the appearance in a radiograph does not reflect the functional condition of the joint surfaces (Pullinger et al. 1990) nor is it necessarily associated with clinical symptoms (Pereira et al. 1994b). The actual contour of the cartilage agrees with the bone contour seen in the radiograph in only 14% of joints (Pullinger 1993). In addition, pronounced radiographic changes were found in the temporomandibular joints of up to 90% of asymptomatic patients (Muir and Goss 1990a, b).

368 Juvenile chronic arthritis
Panoramic radiograph of a 10-year-old with chronic juvenile arthritis. Approximately 10% of children with this disease and near normal formation of the facial bones exhibit degenerative changes in the condyles (Pearson and Ronning 1996). In patients with severe skeletal changes ("bird-face retrognathism") the condyles always show advanced resorption. Early functional treatment can improve the skeletal problems (Pedersen et al. 1995, Paulsen 1997).



369 Coldenhar syndrome
Panoramic radiograph of a 6-year-old with Coldenhar syndrome (oculoauriculovertebral dysplasia). While the right ascending ramus and condyle have developed normally, on the left side there is underdevelopment and shortening of the condylar process. In patients with syndromes, the extent of involvement of the temporomandibular joint is of special interest because this determines the type of treatment (functional jaw orthopedics, Herbst hinge appliance, distraction osteogenesis, reconstructive dentistry).

370 Pyknodysostosis
A 56-year-old man with a spontaneous fracture of the mandible associated with pyknodysostosis. Pyknodysostosis is a rare form of sclerosing osseous dysplasia with an autosomal recessive inheritance (Maroteaux and Lamy 1962, Karkabi 1993). The temporomandibular joints themselves are usually not affected (Yamada et al. 1973, Zachariades and Koundouris 1984), but the osteomyelitis that frequently accompanies it can sometimes mimic a temporomandibular joint problem (Iwu 1991, Schmitz et al. 1996).

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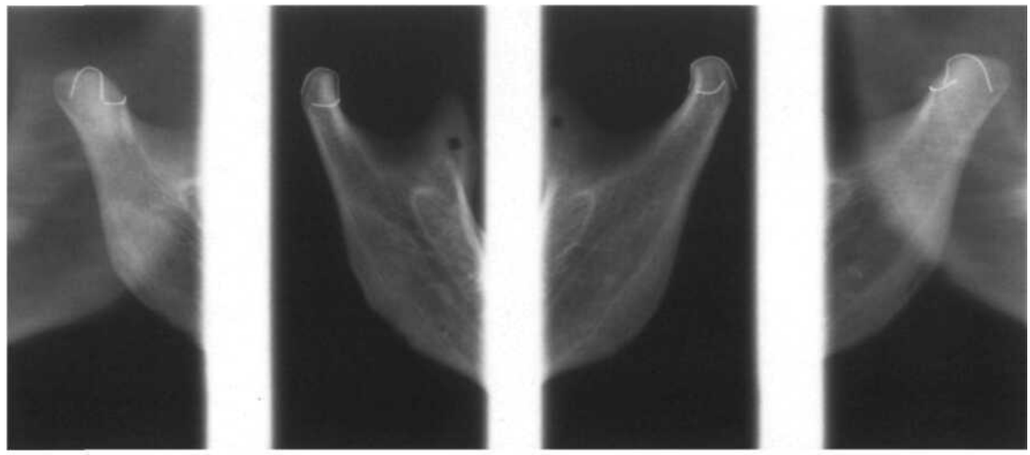
Portraying the Temporomandibular Joint with Panoramic Radiograph Machines

For several years supplementary programs that are supposed to allow specific views of the temporomandibular joint have been made available for panoramic radiographic machines. But in most of these programs the ascending ramus is pictured only as a segment in the same projection used for a conventional panoramic radiograph. Other programs make images of the condyle from two different viewing angles, or offer the ability to make the exposure with the jaws either closed or at maximum opening. The misleading term "functional panoramic radiograph" is sometimes used in the literature.

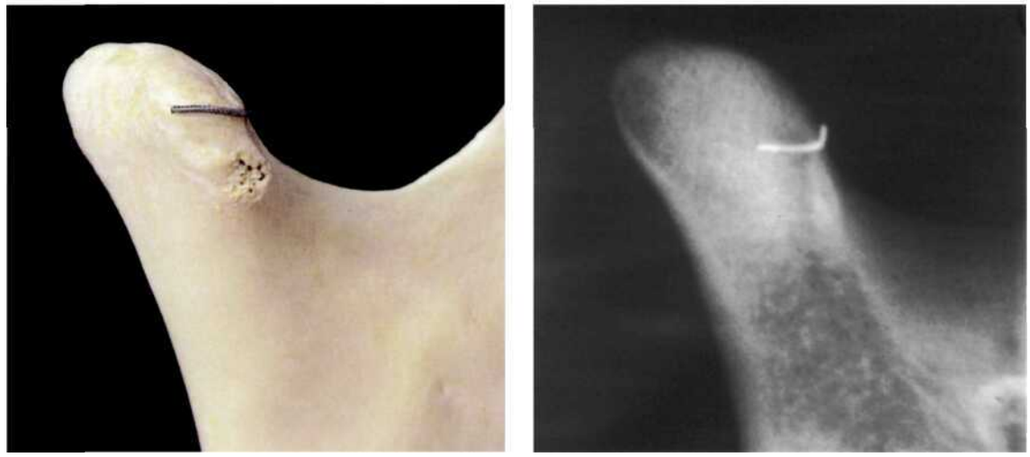
Fundamentally, there is no *compelling medical indication* for any of these modifications. In some programs the orbital movement is modified so that the condyles lie in a better position within the parabolic imaging plane, and this does produce a sharper image (Chilvarquer et al. 1988). Nevertheless, in many patients this technique results in a faulty picture because the condyles tend to "wander" out of the prescribed field of the radiograph. Furthermore, considering the increased radiation dose, there is no indication for exposures made with the mouth both closed and open!



371 Biaxial radiograph of a temporomandibular joint specimen (from Gendex)
Biaxial radiographs of the ascending rami of a macerated mandible. Exposures of the condyles were made at a 0° projection angle *(inner radiographs)* and at a 40° projection (outer *right and left).* It can be seen near the edge of the right picture that the image of the left condyle is distorted posteriorly. At this angle parts of the contour of the condyle are hidden and so cannot be evaluated correctly. The vertical wire marks the central sagittal plane of the condyle and the horizontal wire outlines its lateral portion.

372 0° projection with the temporomandibular joint program
Left: A macerated right condyle. The wire marks the lateral boundary of the former fibrocartilaginous articular surface. With a 0° projection the path of the rays is parallel with the long axis of the condyle. Below the wire an enlarged lateral condylar pole (arrow) can be seen.

Right: Radiograph of the same condyle. A part of the articular surface is superimposed over the condylar process.



373 40° projection with the temporomandibular joint program
Left: The same condyle as shown in Figure 372, but now in a 40° projection. Here the transverse extent of the articular surface can be seen more clearly. Compared with the conventional angulation, this provides a different and perhaps broader view of the joint surface. However, because it provides no information about the fibrocartilaginous articular surface, it has no influence on treatment decisions.

Right: Radiograph of the same condyle.

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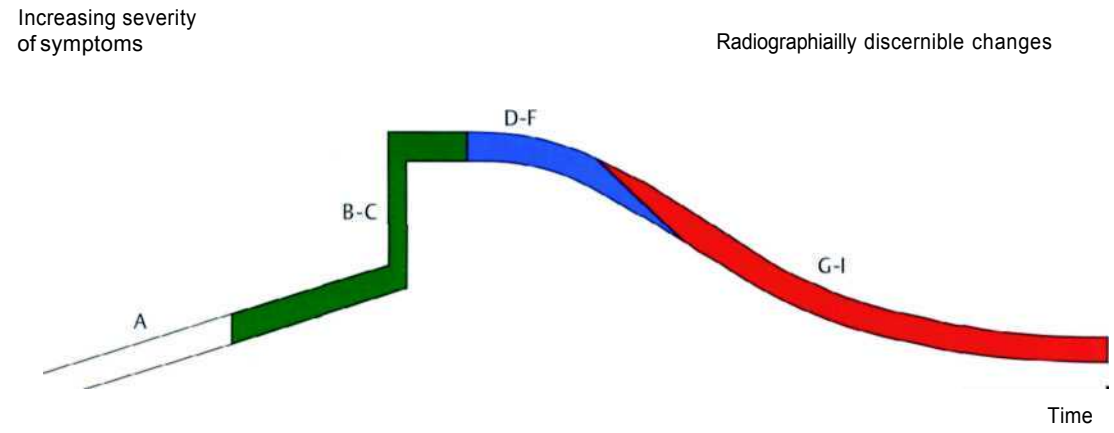
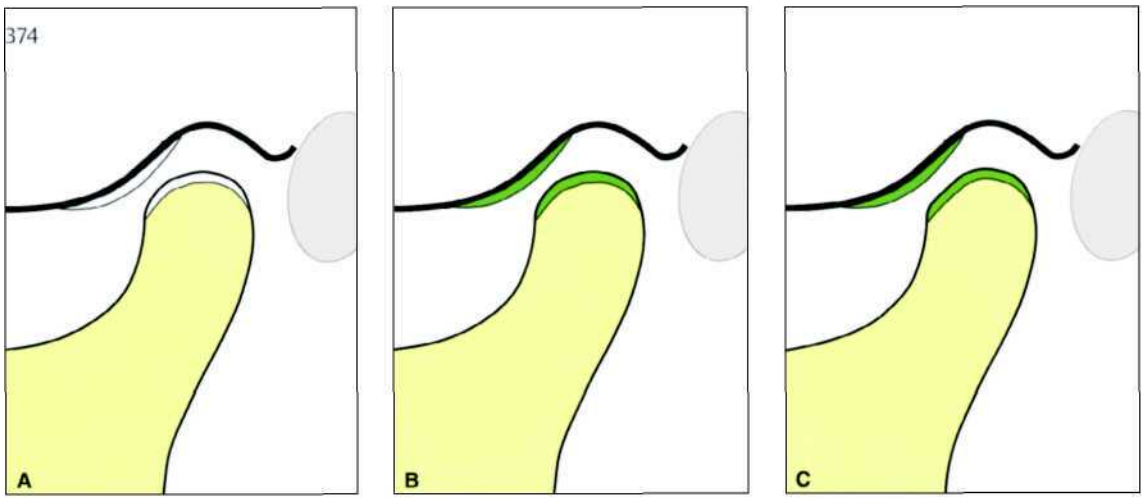


374 Degenerative joint changes (from Hatcher and Lotzmann 1992)

Radiographic representation of joint surface changes has two significant disadvantages:

- It does not show adaptive processes of the fibrocartilaginous articular surfaces that may permit normal function in spite of the osseous changes.
- Overloading of the joint surfaces can be recognized in a radiograph only after a considerable lapse of time, from stage E to stage C.



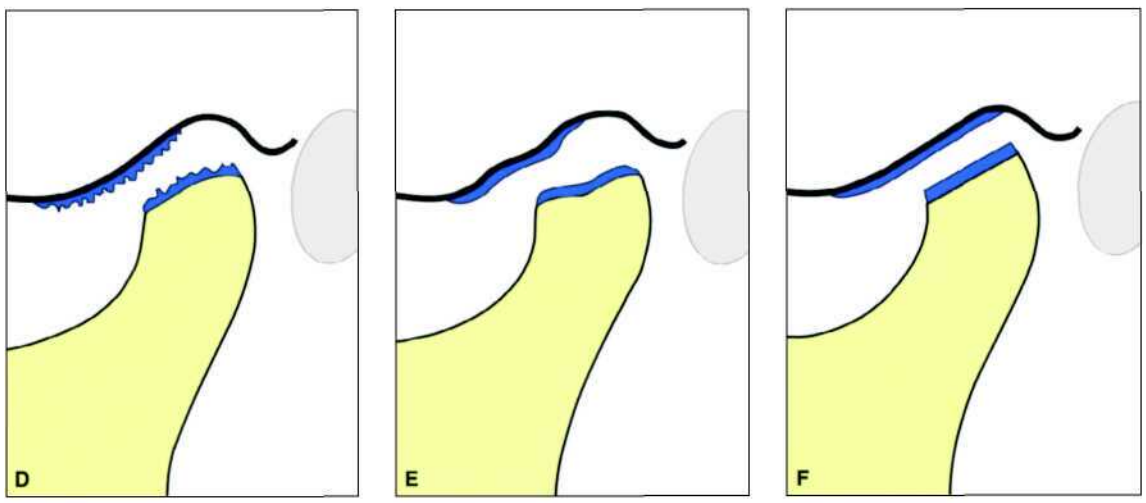
375 Stages A through C

In these stages the joints appear normal in radiographs (panoramic radiograph, Schiiller projection, tomogram, CT).

A Physiological joint with normally functioning articular surfaces.

B Progressive adaptations are expressed as thickenings of the fibrocartiiage that cannot be seen on the radiograph or diagnosed clinically.

C Overloading leads to flattening of the fibrocartilage.

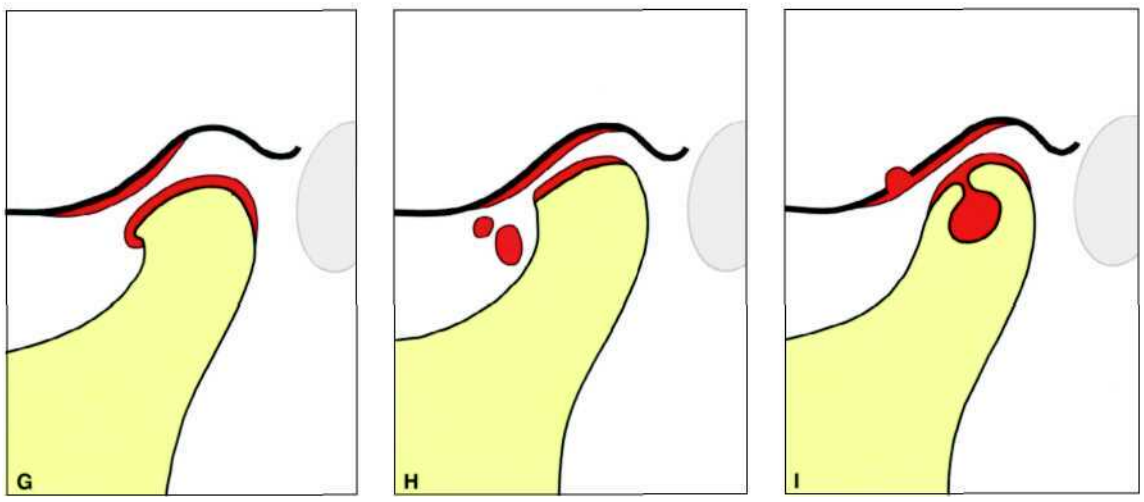


376 Stages D through F

D With further chronic overloading of the articular surfaces, cartilage matrix is resorbed and the contour of the bony condyle becomes flatter. Clinically, slight grating sounds arise at this point.

E With increased loading the joint surfaces become deformed and the bone contours are flattened even more.

F If sufficient adaptation occurs, fibrocartilage will compensate for the osseous changes. Otherwise the rubbing sounds increase in intensity.



377 Stages C through I

Signs of chronic overloading of the joint surfaces that are always visible in the radiograph:

G Formation of a lip at the anterior border.

H Breaking off of free bodies within the joint.

I Formation of subchondral cysts.

Even advanced stages of osseous joint surface changes can sometimes become perfectly adapted through the formation of fibrocartilage. These cases usually have no clinical symptoms and therefore do not require treatment.

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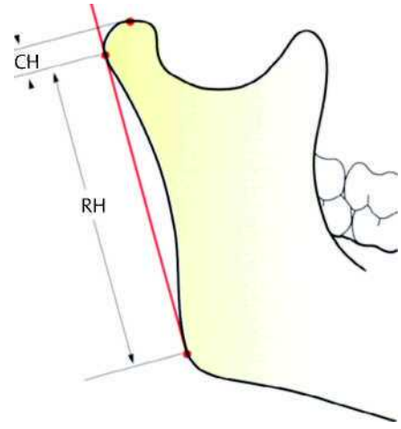
Asymmetry Index

Panoramic radiographs produce an 18-21% magnification in the vertical direction (Larheim and Svanaes 1986). The distortion is even greater when the patient is positioned incorrectly (Tronje et al. 1981). In 1988 Habets and coworkers first proposed a method for determining asymmetries on a panoramic radiograph. Various investigators have used this asymmetry index (AI) in clinical studies (Athanasiou 1989, Bezuur et al. 1989, Schokker et al. 1990, 1994, Miller 1994, Miller et al. 1994).

The principle behind this index is that the vertical heights of the right and left condyle and ramus are measured on a panoramic radiograph and these values are used in the formula AI = [(R-L)/(R+L)] x 100% to calculate the asymmetry index. This is calculated separately for the heights of the condyles and the rami. But as demonstrated in studies by Türp et al. (1995, 1998) and by Ferrario et al. (1997), any conclusions reached by employing the asymmetry index are unreliable.

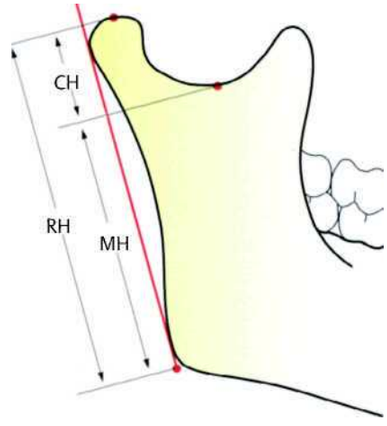
Kjellberg et al. (1994) presented a method to be employed unilaterally on each side to eliminate errors caused by magnification.

378 Habets' asymmetry index
This asymmetry index (AI) is calculated from the formula AI = [(R-L)/R+L)] x 100% in which R and L stand for the values on the right and left sides. AI can be calculated for either the height of the condyle (CH) or of the ramus **(RH).** A difference of more than 3% indicates an asymmetrical relationship. Errors can arise, however, through deviations in the projection angle or positioning of the patient, and these reduce the reliability of the results (Ferrario et al. 1997, Türp et al. 1995,1998).

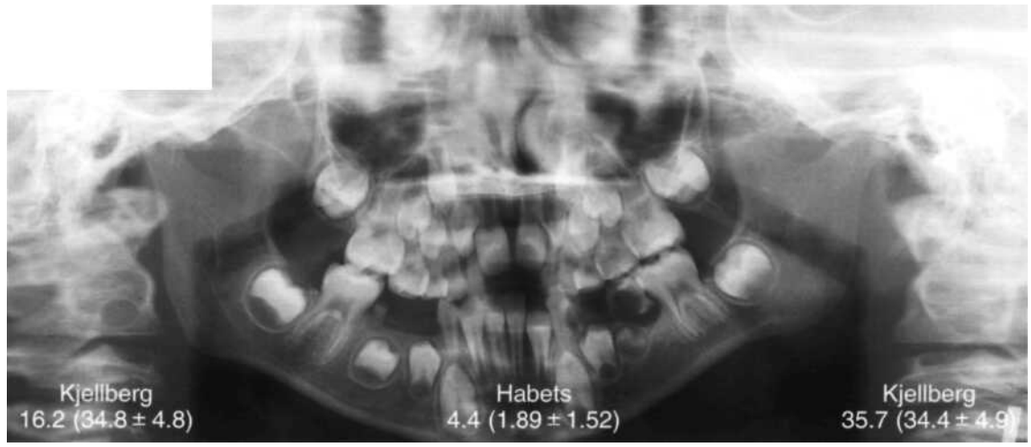


379 Kjellberg's asymmetry index
This determination uses other reference points. By calculaing the quotient of CH:MH or CH:RH in the comparison of the two sides, the magnification error is avoided. The normal values for CH:MH and CH:RH are approximately 35 and 53 respectively. Comparison of the quotients for the two sides allows one to draw a conclusion about asymmetrical relationships in the ascending rami.

CH	condyle height
MH	mandible height
RH	ramus height



380 Asymmetry indices for a patient with hypoplasia of the right condyle
Comparison of Kjellberg's unilateral index *(right and left values with normal values in parentheses)* and Habets' asymmetry index *(central figures).* Even though in this obvious clinical example the values point in the right direction, the clinical significance of these, and the asymmetry index in general, is very questionable because of the biological variations in condylar form (Ferrario et al. 1997) and length (Türp et al. 1998).



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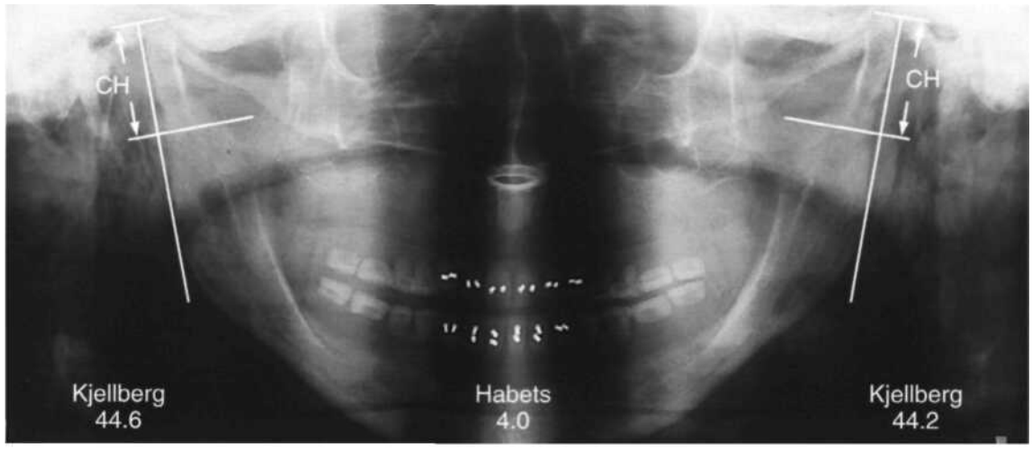
Distortion Phenomena

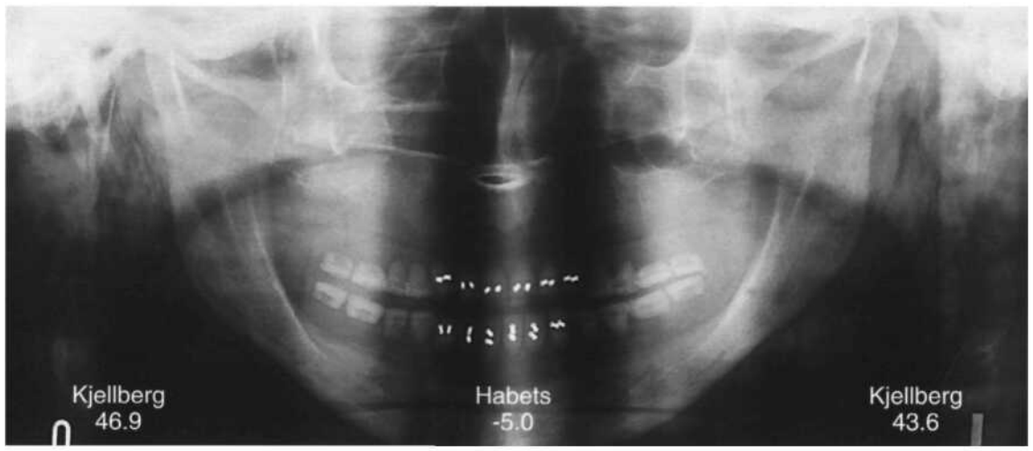
Distortions in the images of the ascending rami and the temporomandibular joints on panoramic radiographs can be traced back to three phenomena (Kaplan 1991):

- In adults the condyles lie outside the plane of focus dictated by the dental arch, and therefore their image appears blurred.
- The central beam is not directed parallel with the long axes of the condyles and this results in an oblique anteromedial view.
- The temporomandibular joint is pictured with a magnification factor and a variable projection angle.

Inaccurate vertical measurements can result from incorrect positioning of the patient's head (extension, flexion, lateral inclination, rotation), measurement errors on the film, or discrepancies in the projection angle. Slight deviations of head position in the machine do not have a great effect on vertical measurements in panoramic radiographs (Xie et al. 1996). Nevertheless, the error in linear measurement can amount to 9-11% (Xie et al. 1997). The agreement of a calculated asymmetry index with the actual anatomical relationships is inadequate (Türp et al. 1995).



381 Correct standard positioning
Example of the asymmetry indices of Habets and Kjellberg on the skull of a 67-year-old full denture wearer with increased condylar height on both sides. When the head is correctly positioned in the x-ray unit, the figures for the Kjellberg index are higher than normal, indicating condylar hyperplasia on both sides. Habets' index is likewise elevated and indicates that the right condyle is longer than the left.



382 Distortion from tilting of the head
The same skull tipped 2° to the right. The resulting distortion causes the Kjellberg index to indicate that the right condyle is longer than the left. Because of the different reference points used, the curious situation arises that according to Habets' index, there is asymmetry with the greater length on the left side. Because of the short length of CH in Habets' method, small errors in measurement will have a greater influence on the asymmetry index.

383 Distortion from rotation of the head
The same skull turned 10° to the left. The distortion here causes the Kjellberg index to indicate that the left condyle is slightly longer than the right. Habets' index still indicates a lengthening on the left side, but within the normal range.
To summarize, these experiments demonstrate that Habets' asymmetry index is more subject to errors than that of Kjellberg.

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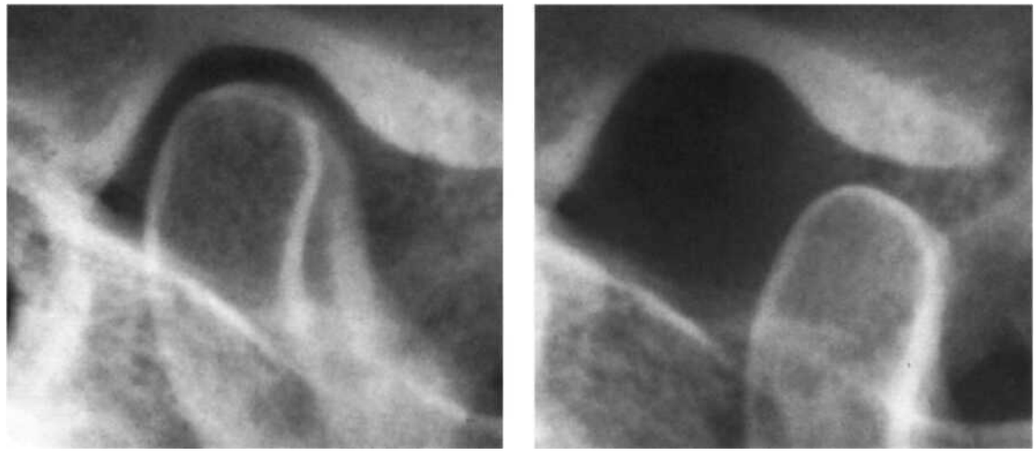
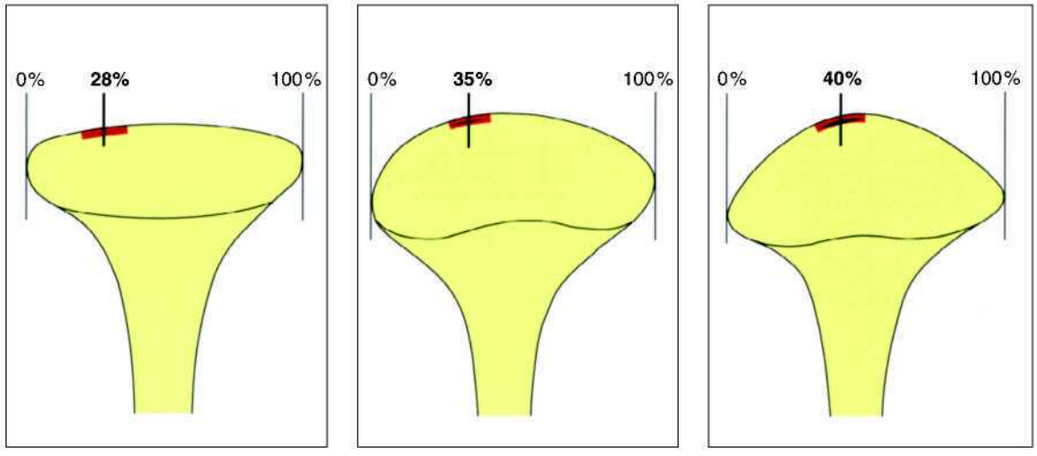
Eccentric Transcranial Radiograph (Schüller Projection)

The technique of the eccentric transcranial radiograph is attributed to Schüller (1905). Over the past decades many modifications of the radiation path have been advocated for improving definition of the joints. However, all the modifications allow only *images of the lateral* (Weinberg 1973) or *centrolateral parts of the joints* (Lauffs and Ewers 1988); abnormalities in the medial part cannot be evaluated on these radiographs (Carlsson et al. 1968). And even in the lateral part, small (<5 mm) bony defects are not always visible in a lateral oblique radiograph (Setz and Fleig 1973).

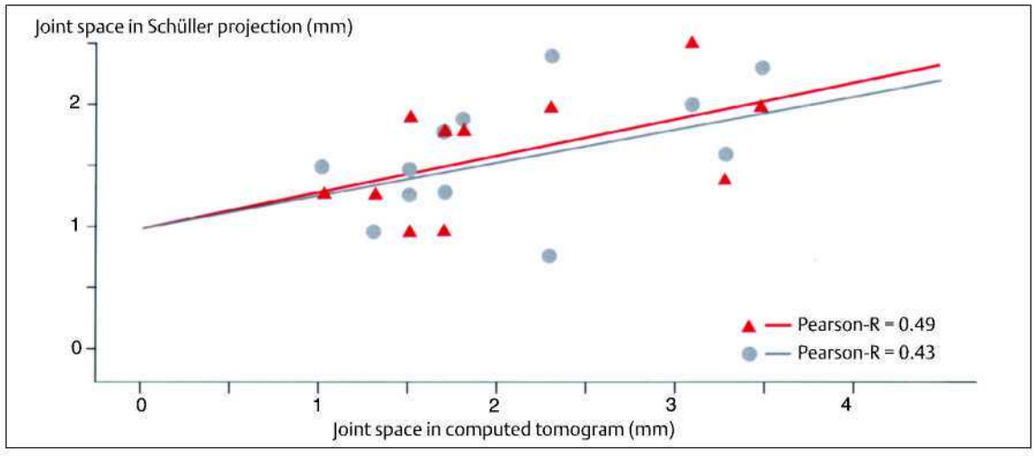
Contrary to earlier clinical studies (Geering 1975, Kundert 1976), it is today agreed that the Schüller projection is contraindicated for finding the position of the condyle in the fossa (Dixon et al. 1984, Aquilino et al. 1985, Preti and Fava 1988, Katzberg and Westesson 1993). The extent to which condylar translation is restricted can be easily determined clinically. Moreover, radiographic monitoring of condylar movement is obsolete. Therefore, there is no longer any rational indication for transcranial radiographs in the diagnosis of functional problems of the temporomandibular joint.



384 Transcranial radiograph of the temporomandibular joint
The right temporomandibular joint of a 52-year-old patient with the jaws closed *(left)* and at maximum opening *(right).* The images of the contours reproduce the relationships in the lateral part of the joint. An accurate evaluation of the joint space in an individual case cannot be made from the radiograph, even if one takes great pains to do so. The exposure in the open position provides no additional information and is superfluous because the extent of condylar translation is already well known from the clinical examination.



385 Depiction of the centrolateral portions of the joint
Which portion of the condyle is outlined in an eccentric transcranial radiograph depends in large measure upon the shape of the condyle (Bumann et al. 1999). The flatter the condyle *(left)* the more the lateral portion will be shown. The greater the convexity of the condyle *(center and right),* the more the image will represent portions nearer the center. However, the bony contours of the condyle do not necessarily agree with the contours of the fibrocartilage (Klein et al. 1970, Pullingeretal. 1990,1993).



386 Correlation of the joint space width in Schüller projections and computed tomograms
Modifications of the Schüller (1905) projection by Lindblom (1936), Palia 1976), and Krenkel et al. (1982) and a consistent exposure technique using the appropriate cephalostat (Hanel 1974, Mongini and Preti 1980) are supposed to make an accurate evaluation of the joint possible. However, the correlation of individualized (red) and average-value (gray) projections with the actual joint space measured on a CT is not adequate. The Pearson-R correlation should be at least 0.7.

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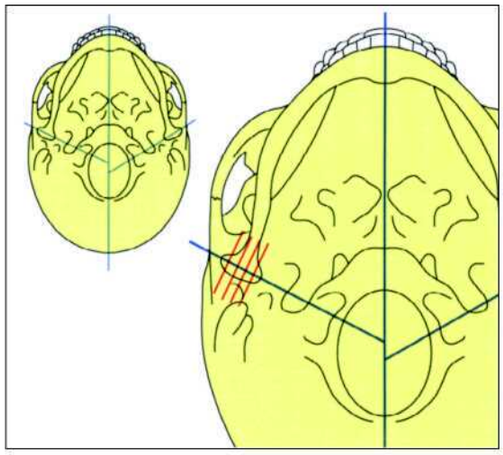
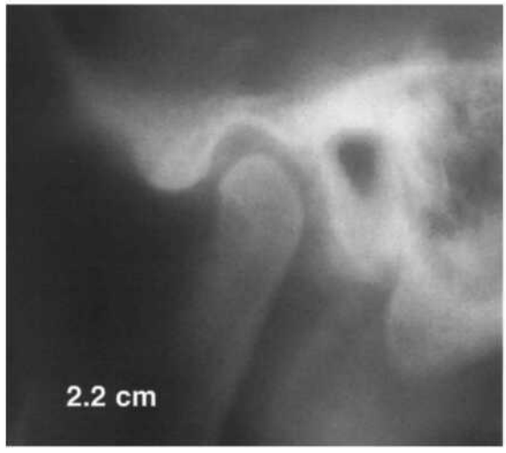
Axial Cranial Radiograph According to Hirtz and Conventional Tomography

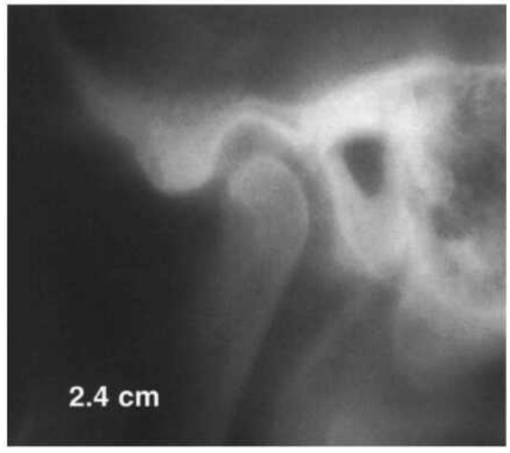
Tomograms were first used as a diagnostic measure for the temporomandibular joint by Petrilli and Gurley (1939). Compared with panoramic radiographs, they have a higher specificity for diagnosing degenerative changes in the joint surfaces (Ong and Franklin 1996). Under the microscope, erosive lesions are found twice as frequently on the temporal portion of the joint as on the condyles (Flygare et al. 1995). However, lesions on the condyle tend to be more pronounced and are therefore diagnosed more frequently on the radiograph. Tomographic methods are not well suited for detecting early stages of erosion (Flygare et al. 1995). Because of their high level of radiation exposure and their questionable therapeutic significance, the indications for tomography of the temporomandibular joint are very limited; it should be employed with reservations. Tomograms are very popular in North America for legal documentation. While some authors (Pullinger and White 1995, White and Pullinger 1995) emphasize their diagnostic importance, others (Eliasson and Isacsson 1992, Callender and Brooks 1996) call this into question.

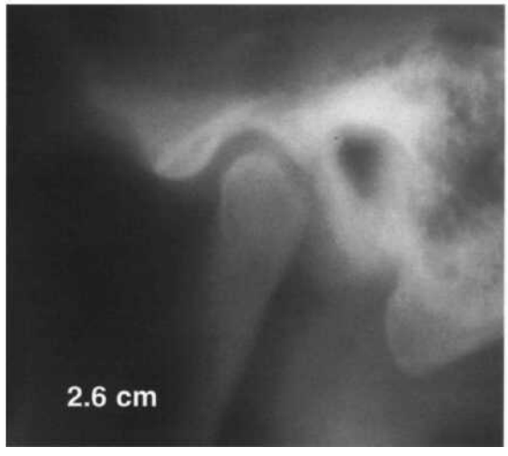


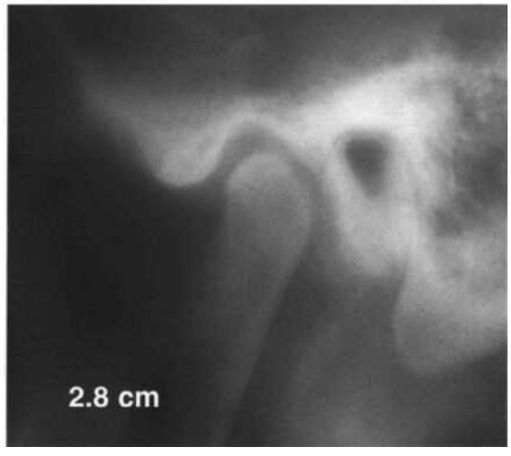
387 Axial cranial projection
Left: Schematic drawing showing the temporomandibular joints in an axial cranial projection. There is no correlation between a greater intercondylar angle and radiographically visible degeneration of the condyles. The angle is significantly greater, however, in patients with painful joints. The intercondylar angle is likewise increased in patients with disk displacements (Sato et al. 1997).

Right Radiograph of a left temporomandibular joint in the axial cranial projection.









388 Tomography of a left temporomandibular joint
As a rule, an axial cranial radiograph is made first for orientation and is followed by preparation of four tomograms of each joint. Each of the recorded layers is 2 mm thick and their distance from the skin surface is 1.5-3.5 cm, depending on the thickness of the subcutaneous fatty tissue. In the case shown here the slices lie at depths of 2.2, 2.4, 2.6, and 2.8 cm.
This representation of the temporomandibular joint provides reliable information about bony changes in the region of the fossa and condyle. Dimensional changes in the joint space make it impossible to draw any reliable conclusions about "joint compression" and "distraction" and therefore should not be used as the basis for therapeutic measures. Here, as with the previously described technique, there is no reason to make an exposure with the jaws open because that would provide no additional diagnostic information, and the open-position radiographs are ifrelevant as far as the treatment is concerned.

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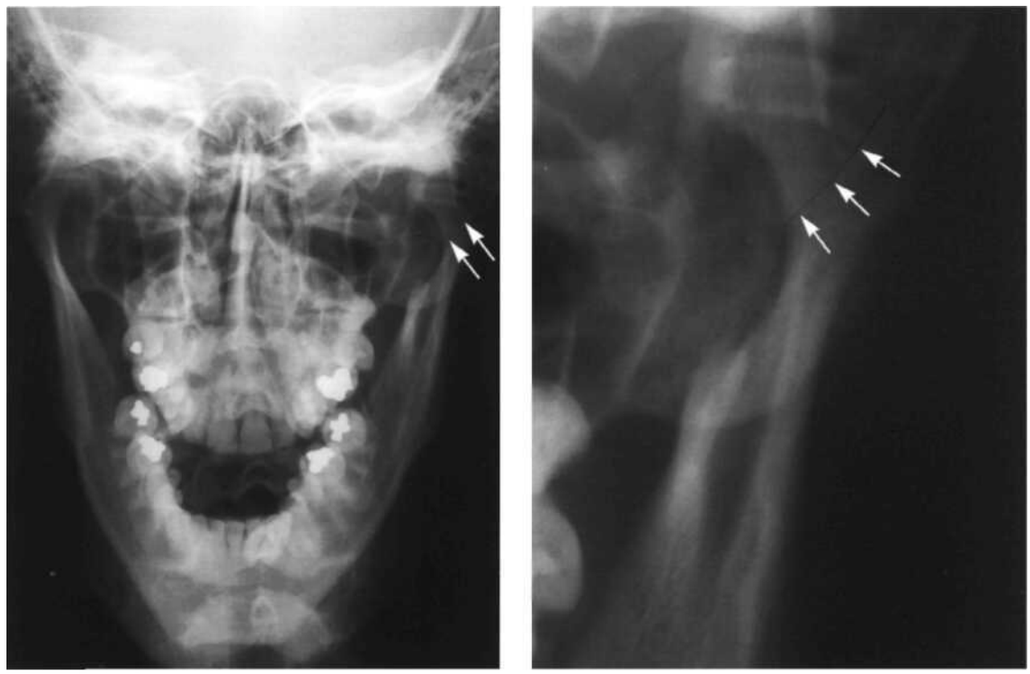
Posterior-Anterior Cranial Radiograph according to Clementschitsch

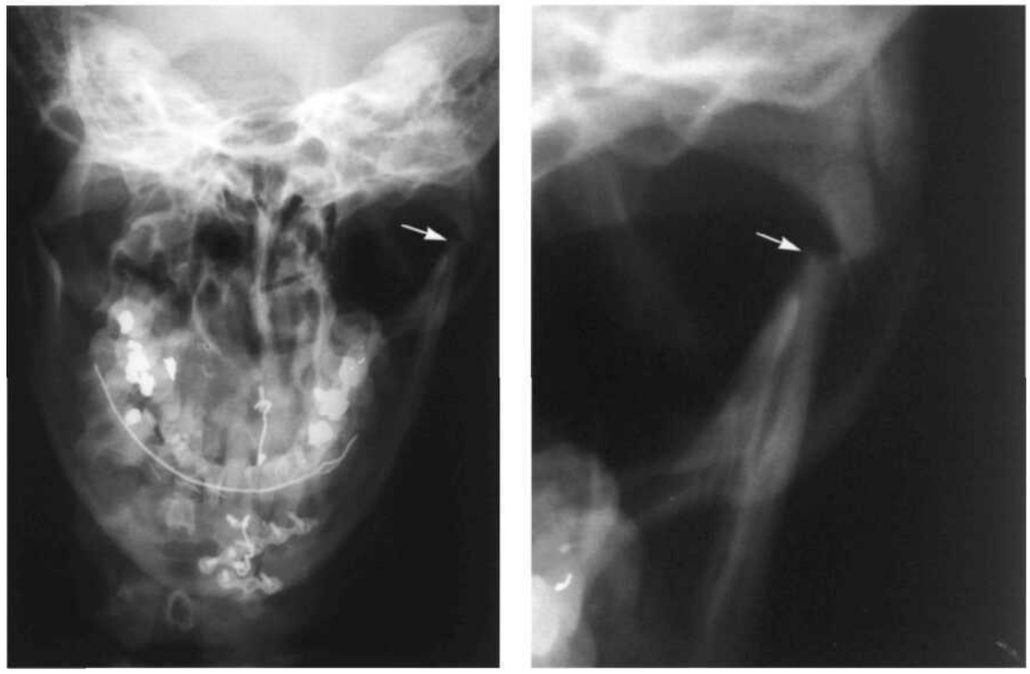
Frequently, fractures in the region of the ascending ramus of the mandible and the temporomandibular joint cannot be adequately evaluated in radiographs made in one single plane (Moilanen 1982). An additional posterior-anterior cranial exposure (Clementschitsch 1966) is chosen primarily when there is suspicion of fracture of the mandible or neck of the condyle. Because of the eccentric path of the rays (Rother and Biedermann 1978, Pasler 1991) and the opening of the jaws, there is little or no overlapping of other bony structures over the condyles. Therefore intracapsular fractures and the extent of luxation of the proximal fragment of a condylar neck fracture can be displayed well in this second plane.

Through the modern techniques of three-demensional reconstruction, however, Clementschitsch's posterior-anterior cranial radiograph is becoming increasingly supplanted by the computed tomogram (Kahl et al. 1995). Apart from this, patients who have a suspected fracture of the neck of the condyle and bleeding from the outer ear should have a CT scan directly to reduce the total dose of radiation, because often there is also a fracture of the temporal bone that otherwise might go undetected (Avrahami and Katz 1998).



389 Intracapsular fracture
Left: Full frontal view radiograph showing an intracapsular fracture (arrows) in the left joint of a 17-year-old patient. The clinical symptom was pain in the temporomandibular joint region following a traumatic blow.

Right: Enlarged section of the left temporomandibular joint region. Here the line of disrupted continuity (arrows) can be seen more easily. Depending upon the degree of dislocation, intracapsular fractures are treated either conservatively through intermaxillary fixation or treated surgically. After a surgical reduction, the fragments are immobilized with wire, miniscrews, or resorbable pins (Rasse et al. 1991). If untreated, an intracapsular fracture could lead to osteomyelitis (Sanders et al. 1977).



390 Fracture of the neck of the condyle
Left: Full facial view showing bilateral fractures of the condylar processes in a 38-year-old male patient. The paramedian fracture of the mandible has already been treated surgically.

Right: Enlarged section of the left temporomandibular joint region. In adults the fragments will usually heal by forming a bony union in the dislocated position (Choi 1996). Surgical repositioning of the condyle without fixation results in healing with a slight medial inclination of the condyle. Subsequently, 48% of these condyles will show no alteration in their morphology (Iizuka et al. 1998).
Following condylar neck fractures in children, up to 77% will regain a normal physiological condylar shape through remodeling (Kellenbergeretal. 1994).

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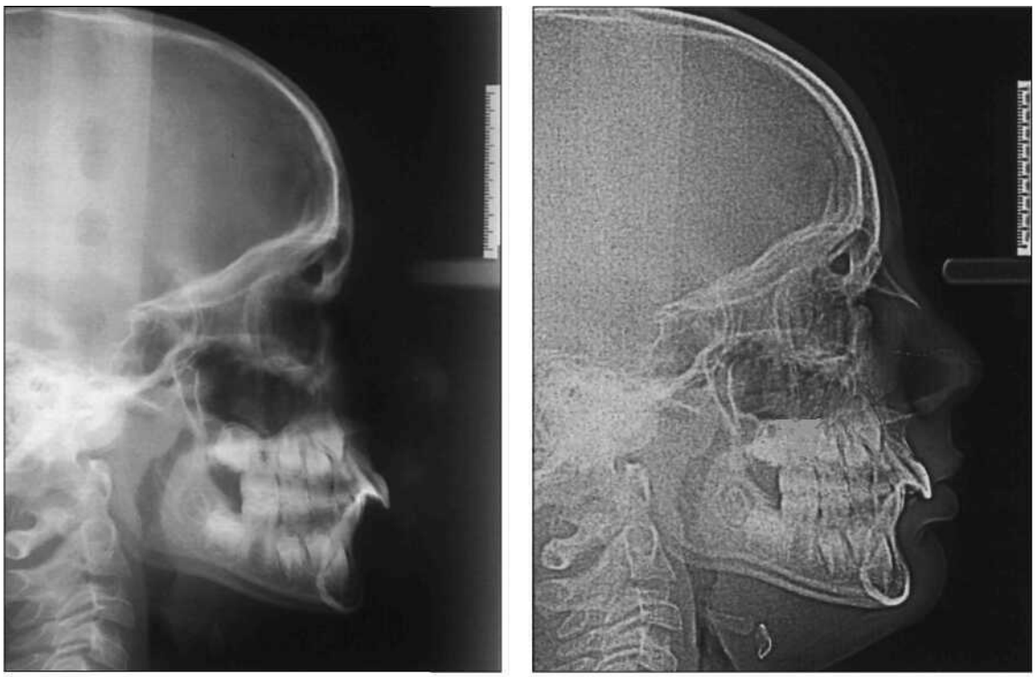
Lateral Transcranial Radiograph

The lateral transcranial radiograph has no use as a diagnostic tool for the temporomandibular joint but does reveal the condition of the craniovertebral, craniofacial, and craniohyoidal complexes (Solow and Siersbaek-Nielson 1992, Kluemper et al. 1995, Huggare and Houghton 1996).

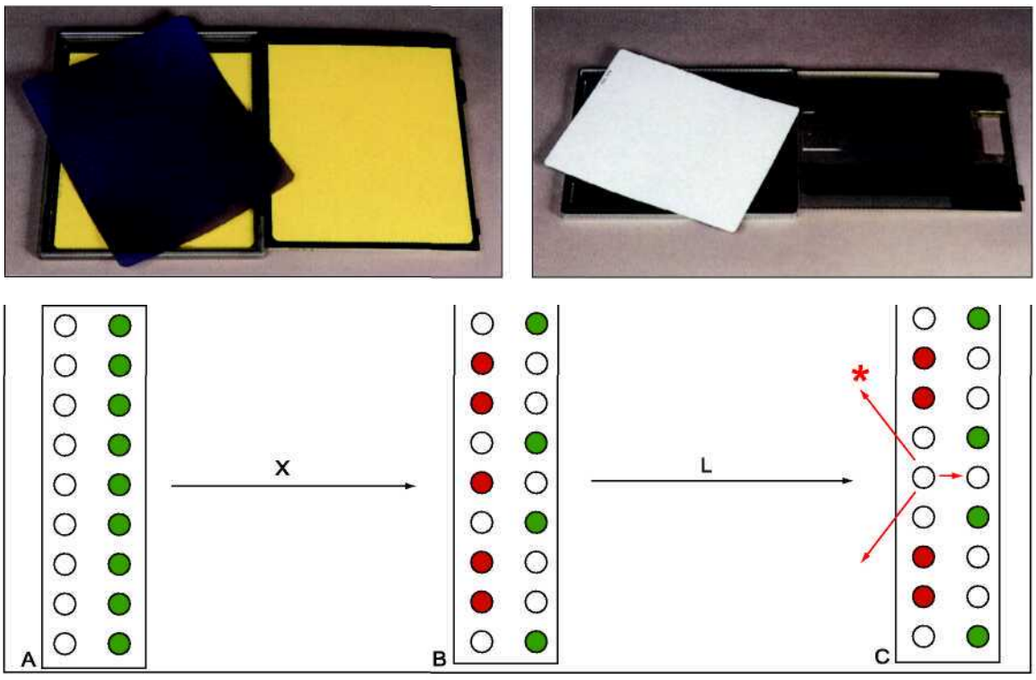
When distraction osteogenesis is planned to lengthen the ascending rami of the mandible (Stucki-McCormick 1998), a lateral transcranial radiograph is necessary to determine the distraction vector.

O'Ryan and Epker (1984) and Burke et al. (1998) were able to identify a posterior loading vector based upon the distribution of trabeculae in the condyle. In a cephalometric analysis, this is accompanied by an increased mandibular angle and mandibular plane angle. Similar findings have also been described in patients with Angle Class III occlusions and anterior disk displacements (Muto et al. 1998, Brand et al. 1995, Dibbets and Van der Weele 1996, Nebbe et al. 1997, Bumann et al. 1999).



391 Conventional versus digital
Left Conventional lateral transcranial radiograph. To capture the centric mandibular position one should not, as frequently described, slide the teeth from the incisal contact position to the retruded contact position, but should rather make the radiograph in centric condylar position after appropriate preliminary treatment.

Right: Digital lateral transcranial radiograph of the same patient. While the reproduction of the osseous reference points is virtually the same, the soft tissues show up much more clearly because of the 75% reduction in radiation exposure. This advantage has been corroborated in similar studies (Eppley and Sadove 1991, Bumann et al. 1999).



392 Cassettes for the conventional and the digital radiographic techniques
Above: Cassette-film combination for conventional lateral transcranial radiograph *(left)* and cassette with a special luminescent screen for digital images *(right)*.

Below: A schematic diagram showing the operation of the screen for digital radiographs (PCR, Gendex): X-rays (X) raise electrons in the screen to a higher energy level. As the screen is swept by a laser (L) the excited electrons return to their base energy level and luminescent rays (*) are emitted.

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Computed Tomography of the Temporomandibular Joint

CT (Suarez et al. 1980) is not one of the routinely used radiographic examination techniques for the temporomandibular joint. It serves primarily as an *expanded diagnostic tool for fractures, advanced arthritis, ankylosis, and tumors* (Brooks et al. 1997). Thanks to its high resolution, it is especially suited for diagnosing bony abnormalities (Manzione et al. 1984). Although it can reveal the disk, MRI is preferred for a more specific evaluation of the disk (Helms and Kaplan 1990, Larheim 1995).

A distinction is made between two exposure techniques (Manzione et al, 1984, Thompson et al. 1984): axial slicing with computation of an image in the sagittal plane and direct sagittal slicing. For a long time the *direct sagittal scan* was associated with a very uncomfortable patient position, but with more modern equipment the patient can now be positioned more comfortably.

Spiral CTs permit a more rapid and precise acquisition of data. They also reduce the radiation exposure and are advantageous for multiplanar slices and three-dimensional reconstructions (Tello et al. 1994).

393 CT scanner
A typical model of CT scanner for the making of spiral (helical) CTs. The computer tomograph unit CT Twin shown here and manufactured by Picker (formerly by Elscint), unlike other scanners, can measure two layers simultaneously during a rotation of the detector system (Seifert et al. 1997). This so-called *dual sliced mode,* in contrast to the so-called fused slice mode, allows considerable reduction in both the examination time and the radiation exposure.

Photograph courtesy of J. Hezel

394 Scan parameters
Table of the well-tested scan parameters for the axial spiral scan. The figures apply to the CT Twin scanner.

Axial scan

kV	mAs	Slice thickness	Increment	Resolution	Filter	Magnification
120	130	1.1mm	1	high	**D**	**0**

Axial spiral scan

kV	mAs	Slice thickness	Increment	Resolution	Filter	Magnification	Pitch
120	130	1.1mm	0.6	high	D	0	0.7

395 Radiation exposure
Radiation dose (values in mCy) delivered to different organs during a computed tomographic examination of the temporomandibular joints. The figures are derived from the work of Christiansen et al. (1987) (*) and van der Kuijl (1992)

C = condyle
M = mandible

	Thyroid	Brain	Eye lens	Hypophysis	Bone marrow
Orientation slice	**0.20**	**0.90**	**0.65**	**1.20**	**1.15**
Dynamic axial scan	**1.40**	**1.60**	**3.90**	**9.35**	**63.45**
High resolution scan	**0.45**	**0.75**	**1.20**	**3.35**	**21.55**
Direct sagittal scan*	**1.55**	**3.85**	**2.95**	**2.35**	**13.45 (C)**
Direct sagittal scan**	**0.35**	**0.095**	**–**	**–**	**0.002 (M)**

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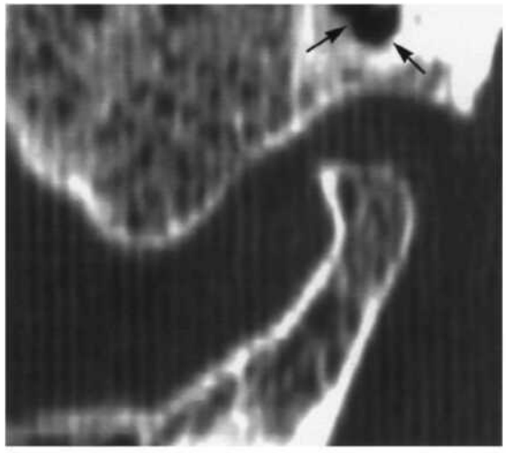
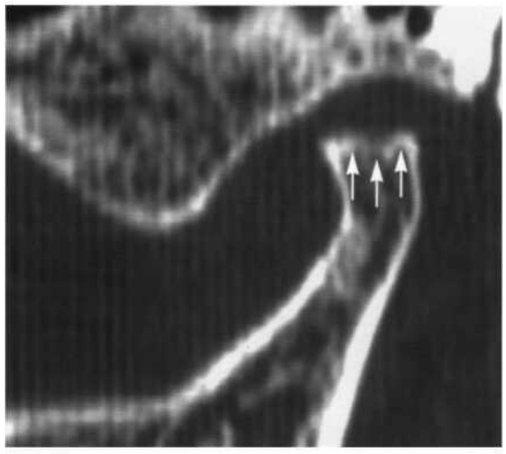
Computed Tomography of the Temporomandibular Joint and its Anatomical Correlation

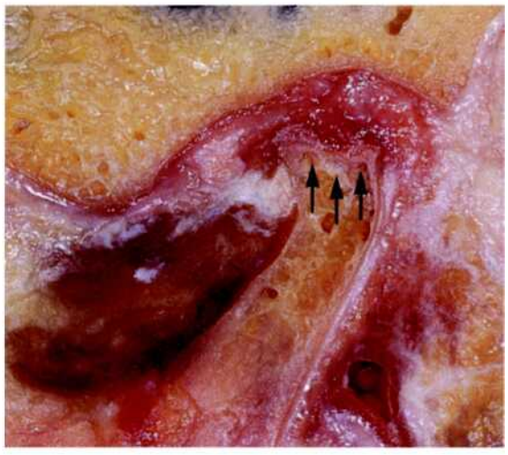
CT is especially suited for *representing the morphology of bone* (Thompson et al. 1984, Westesson et al. 1987, Tanimoto et al. 1990, de Bont et al. 1993, Hu and Schneiderman 1995). Therefore, it is also employed for evaluating therapeutic measures (Fernandez Sanroman et al. 1998, Kawamata et al. 1998) and for planning implant procedures (Westesson 1996, Kraut 1998). However, on small structures with a high degree of curvature, such as the condyle and fossa, the so-called partial volume effect can cause one to overestimate the thickness of the cortical bone by as much as 200% (Ahlqvist and Isberg 1998). For investigating the disk, CT is not the method of choice (de Bont et al. 1993, van der Kuijl et al. 1994). The sensitivity of disk diagnostics with CT scans is 0.86, but because the disk is often confused with the tendon of the lateral pterygoid muscle, specificity is only 0.5. An elevated adsorption of radiation by the disk does provide evidence of hyalinization, calcification, and metaplasia (Paz et al. 1990). Remodeling processes in response to orthodontic treatment are seen as double contours of cortical bone in the fossa and on the condyle (Paulsen 1995).



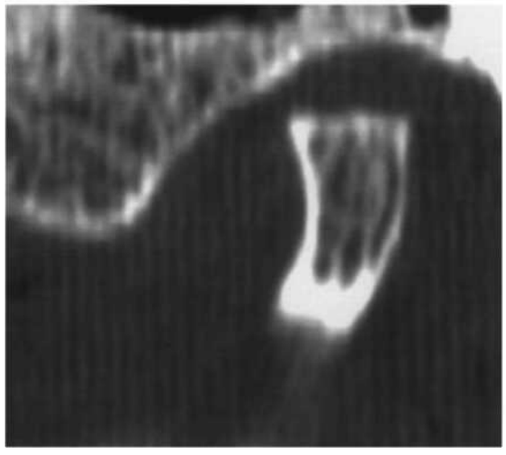
396 Lateral portion of the joint
A computed tomogram and a macroscopic anatomical preparation of the lateral portion of a human temporomandibular joint.
Left: Because the CT machine was not fitted with a soft-tissue window, the soft tissues cannot be identified. The low thickness of the slice causes some of the marrow spaces to appear as cavities (arrows).

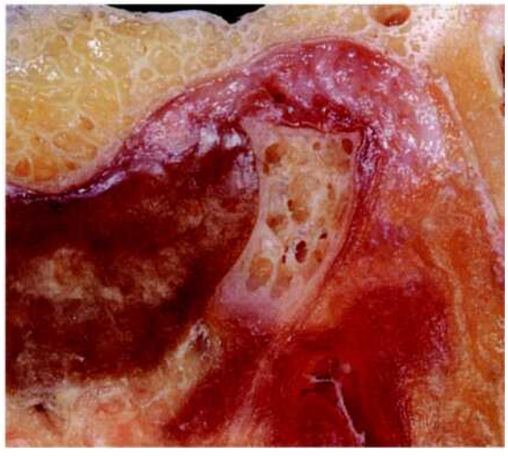
Right: Because in this specimen the insertion of the lateral pterygoid muscle lies farther lateral than usual, part of the tendon (outlined arrows) can be recognized.





397 Central portion of the joint
Pictures of the central portion of the same joint. Notice the precision with which the CT reproduces the contours of the osseous structures (arrows).





398 Medial portion of the joint
In addition to the contours of the fossa and protuberance, the cancellous bone of the condyle is prominently reproduced in the medial slice of the joint as well. The ability of CT to accurately reproduce the bony articular surfaces should not mislead one into thinking that CTs are absolutely necessary for all temporomandibular joint problerns. They are practical for joint deformations associated with syndromes, fractures, ankylosis, or tumors, but all other joint surface lesions can be adequately diagnosed through other clinical procedures (see also p. 68).

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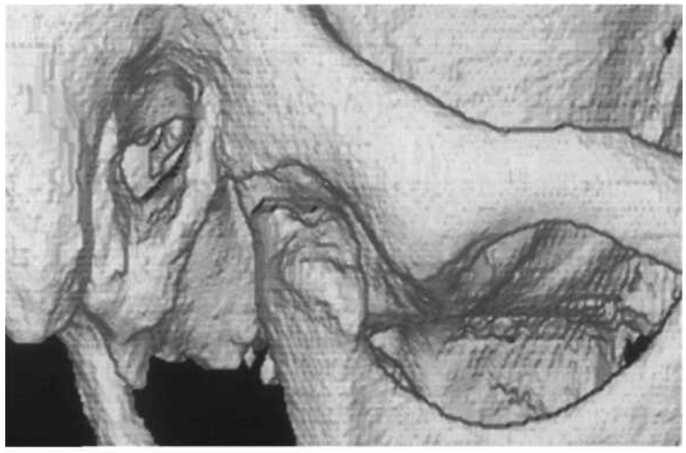
Three Dimensional Images of the Temporomandibular Joint...

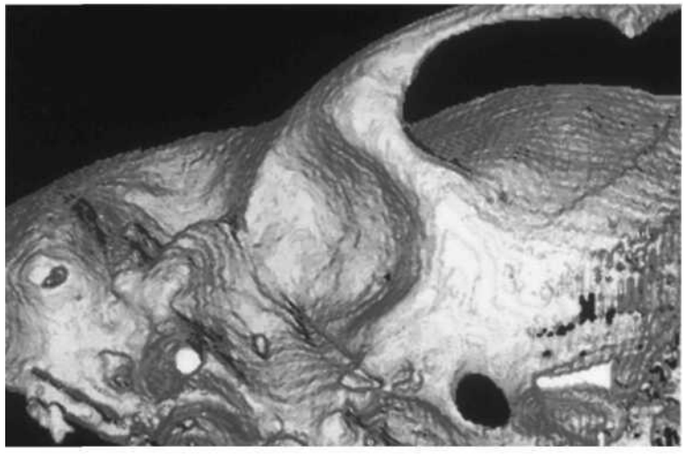
Advances in computer technology have made it possible to create three-dimensional images from single axial or sagittal slices (Ray et al. 1993, Rodgers et al. 1993). This has helped to further improve the ability to make an accurate diagnosis and to more effectively plan treatment prior to surgery (Alder et al. 1995). Measurements on the computer screen can be used with confidence because these values agree with the anatomical measurements (Raustia and Phytinen 1990). The computed spatial objects can be rotated and viewed on the monitor from any direction. With the right software it is also possible to separate the condyle from the fossa. This permits accurate inspection of the medial part of the joint. For better visualization, structures that are of distinctly different shades of gray (measured in Hounsfield units) can even be displayed in different colors.

Three-dimensional imaging of the temporomandibular joint is especially indicated for ankylosis and tumors where it helps the surgeon plan exactly how much tissue to remove. Hyperplasia of the coronoid process is another classic preoperative indication (Honig et al. 1994).

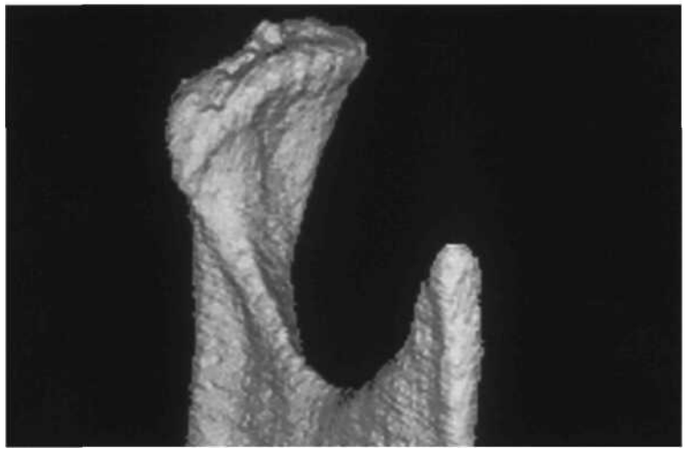
399 Three-dimensional representation of a temporomandibular joint
A three-dimensional image of the joint can be reconstructed from CT measurement data. Further detail can be seen by separating the condyle from the fossa. Special software (Denta-CT) is available for the orofacial region and is designed especially for three-dimensional imaging of the alveolar processes (Abrahams and Kalyanpur 1995).



400 Three-dimensional representation of the fossa
An inferior view of the articular fossa from Figure 399 is shown. This view permits scrutiny of the condylar path and the articular eminence. The image can be rotated on the monitor so that the morphology and inclination of the joint pathway can be calculated. This determination has no clinical relevance, however. In edentulous patients the fossa lies more anterior than it does in patients with teeth. Its sagittal position depends on how long the patient has been edentulous (Raustia et al. 1998).



401 Three-dimensional representation of the condyle
This separate image of the condyle allows inspection of the joint surface. This type of image is only important for primary temporomandibular joint diseases, however. Changes in the articular surfaces due to dysfunction can be adequately diagnosed clinically and do not require three-dimensional imaging, as the radiographic findings would not change the treatment.



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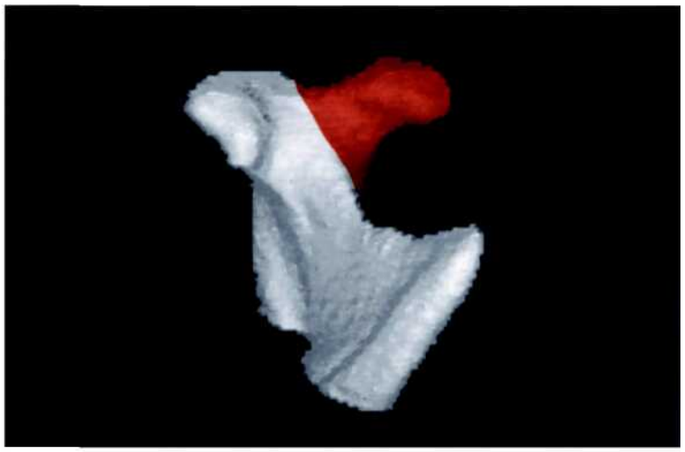
...with the Aid of Computed Tomography Data

Another indication that can be listed for CT with 3-D reconstruction *is fracture of the neck of the condyle in adolescents and adults* (Kahl-Nieke et al. 1994, Avrahami and Katz 1998). The position of the fractured condylar process relative to the ramus can be determined more accurately in a computed tomogram than in a conventional radiograph (Raustia et al. 1990). Only 4.9% of disks remain in the correct relation to the fossa following a fracture of the condylar process (Yamaoka et al. 1994). The much more important disk-condyle relationship, however, experiences much less disruption (Terheyden et al. 1996). If the fractured segment shows no contact with the ramus, it will frequently become resorbed in children and adolescents and a new condyle is formed through the remodeling process. As a rule, no resorption occurs in adults (Avrahami et al. 1993).

Alhough routine 3-D MRI reconstructions are not yet in widespread usage, they are superior to CT for diagnosing fractures of the neck of the condyle (Bumann et al. 1993, Sullivan et al. 1995, Choi 1997, Oezmen et al. 1998). This is because MRI better reveals the disk-condyle relationship, which is so important to the course of treatment, and because it requires no exposure to ionizing radiation.



402 Condition 3 years after fracture of the neck of the left condyle
Three-dimensional image reconstructed from CT scans of the condyle of a 14-year-old patient following fracture of the left condylar process of the mandible. The isolated image of the condyle reveals that the anteromedially displaced fragment has healed in the wrong position and a "new" condyle (red) has formed lateral to it.

Left: Reconstructed left joint in a lateral view showing the new formation of a condylar process (red).

403 Inferior view for side-by-side comparison
This caudal view clearly shows the abnormal shape of the condyle in the left joint. The healed dislocated medial fragment and the remodeling in the lateral part (red) have created a V-shaped condyle. In spite of the absence of physiological condylar form, the post-traumatic open bite found in this type of case can be closed through muscular adaptation during functional orthodontic treatment (Kahl et al. 1995, Choi 1996).

404 Changes in the joint pathway following fracture of the neck of the condyle
Digital subtraction of the condyles allows inspection and comparison of the two fossae. The V-shaped left condyle has led to flattening of the articular protuberance in the left joint (arrows). The right joint exhibits normal contours (outlined arrows). The joint pathway may be flattened by both a reduction of the eminence and apposition of bone on the roof of the fossa (Sahm and Witt 1989).

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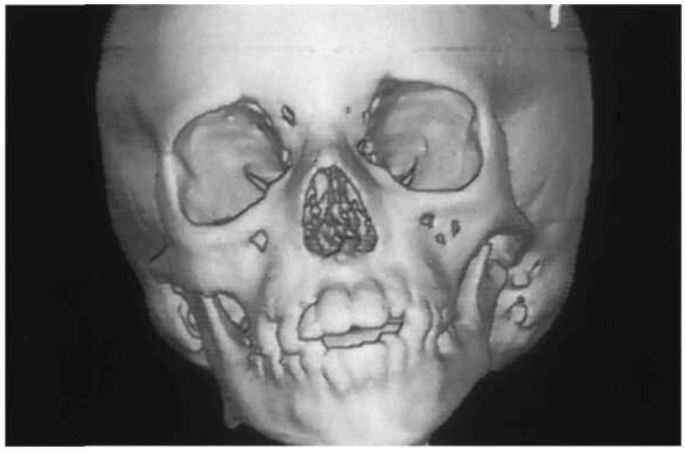
Three-Dimensional Reconstruction for Hypoplastic Syndromes

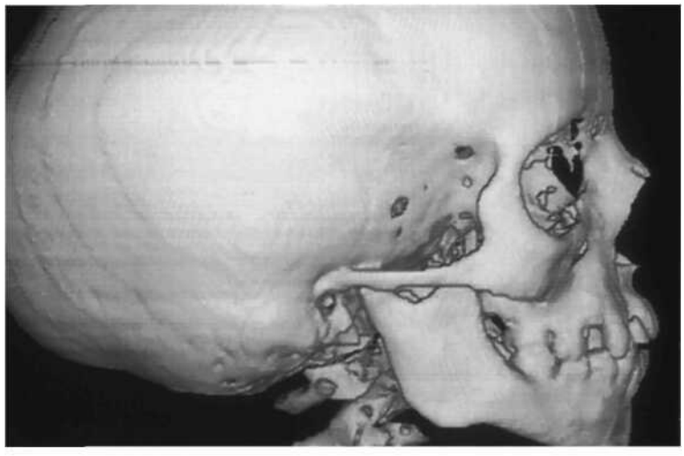
Three-dimensional images from CT data are finding wide application for cases requiring *surgical reconstruction of hypoplastic structures* associated with syndromes and treatment of tumors in the facial skeleton (Linney et al. 1989, Mutoh et al. 1991, Carls et al. 1994, Eufinger et al. 1997, Jensen et al, 1998). In all disease entities with hypoplasia of the mandible or temporomandibular joint (e.g. Goldenhar syndrome, craniofacial microsomia, Treacher Collins syndrome, micrognathia, Pierre Robin syndrome), the three-dimensional CT is very helpful in planning the size of a transplant or determining the distraction vector (Stucki-McCormick 1998). With computed reconstruction, volumetric differences can be determined, and this can be quite important when using appliances for multiplanar distraction osteogenesis (Roth et al. 1997). In addition to understanding the extent of hypoplasia in the primarily affected structure, it is important for the clinician to know whieh other structures are affected by secondary adaptation. A typical example of this is deviation of the maxilla in the frontal plane in response to unilateral mandibular hypoplasia.

Coldenhar syndrome

405 Frontal view
Three-dimensional reconstruction of the cranium and facial skeleton of an 8-year-old boy. Because of hypoplasia of the left ascending ramus the mandible has deviated to the left and the maxilla has undergone secondary adaptive changes. The more pronounced the adaptive changes, the more important it is to institute functional therapy in addition to surgical correction (Behniaetal. 1997).



406 Right temporomandibular joint
Three-dimensional reconstruction of the unaffected right side. The relationship between the ascending ramus and the condylar process is almost normal. The condyle shows a slight flattening inconsistent with the patient's age. The external auditory meatus and glenoid fossa show no deviation from the norm. Even though it is theoretically possible to represent the muscles of mastication in a CT, MRI is to be preferred for evaluating muscular changes.



407 Left temporomandibular joint
On the left side, the mandible is noticeably underdeveloped. This affects the height of both the body of the mandible and the ascending ramus. In addition, both the condylar process and the articular eminence are hypoplastic. The osseous external auditory meatus is obliterated. While planning the surgical operation for distraction osteogenesis, the shapes of the ascending ramus and the condylar process are especially important for determining the exact distraction vector.

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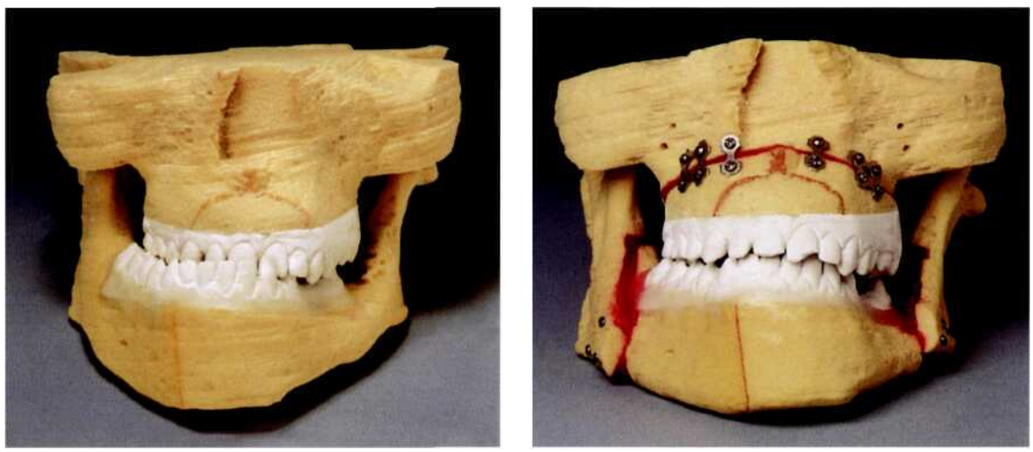
Three-Dimensional Models of Polyurethane Foam and Synthetic Resin

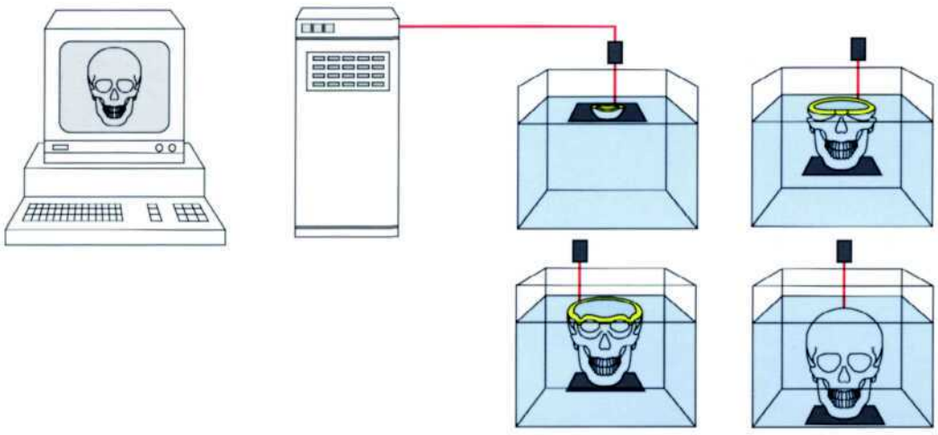
Three-dimensional models of the skull are quite helpful as an additional diagnostic tool and for simulating the surgery planned for dysgnathia or congenital syndromes (Vannier 1991, Ayoub et al. 1996, Hibi et al. 1997). They facilitate exact anatomical repositioning, shorten the operating time, contribute to an improved postoperative result, and thereby reduce the need for secondary operations (Kermer et al. 1998). The fabrication of milled models was first described by Brix et al. (1985). Stereolithography has been used since the beginning of the 1990s (Mankovich et al. 1990, Sato et al. 1998). These models are accurate to within 0.25-0.47 mm (Barker et al. 1994, Lindner et al. 1995). Measurements on three-dimensional models before and after mandibular advancement surgery revealed an average increase in the distance between the condyles of 2.9 mm and in the distance between the coronoid processes of 6.9 mm (Schultes et al. 1998). Because of its shorter production time and lower cost, milled polyurethane foam models are given preference for routine cases. If, however, reproduction of bony details and hollow spaces is necessary, then Stereolithography is the method of choice (Kermer et al. 1998, Sailer et al. 1998, Santler et al. 1998).



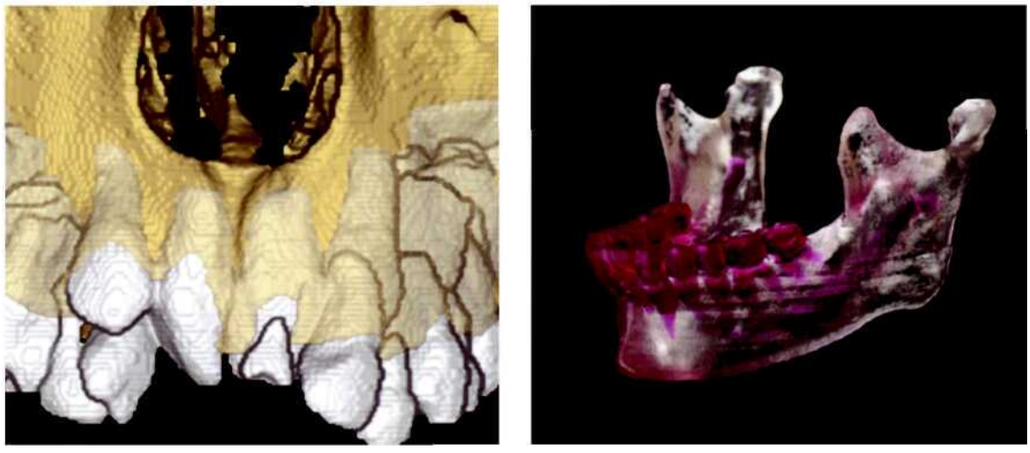
408 Polyurethane foam models
Left The CT data guides a special milling machine that carves a model of the jaws from a block of polyurethane foam (Caggl et al. 1998).

Right: The planned operation can be simulated on the models and the fit of the osteosynthesis material tested. This will substantially reduce the operating time. This procedure is indicated especially for patients with asymmetries (Fuhrmannetal. 1994).

Collection of B. Fleiner



409 Principle of stereolithography
In Stereolithography a UV laser is guided by the three-dimensional CT data set. The laser travels over a container of liquid synthetic resin, polymerizing a trail in the liquid material. Then a computer-guided table is submerged by the thickness of the polymerized layer and the next slice is polymerized by the laser. These steps are repeated until the entire model has been polymerized.



410 Stereolithographic models
Left: Monitor image of a three-dimensional model of a maxilla with retained incisor teeth from a 12-year-old patient. Modern software makes it possible to color the clinical crowns and the submerged roots and teeth differently from the bone.

Right: The most recent advances in Stereolithographic technology makes it possible to produce multicolored models such as this in which the teeth can be distinguished from the bone (ClearView TM, Medical Modeling Corporation).

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Magnetic Resonance Imaging

MRI is an imaging procedure by which not only bone, but also soft-tissue structures can be reproduced in detail by employing static and dynamic magnetic fields. Bloch et al. (1946) and Purcell et al. (1946) were the first to describe the principle of magnetic resonance. Clinical application was not possible, however, until the discoveries of Damadian (1971) and Lauterbur (1973). Thanks to the development of so-called surface coils, it has been possible since the mid 1980s to study the temporomandibular joint through MRI (Harms et al. 1985, Katzberg et al. 1985). Since then the MRI has developed into the method of choice for evaluating all forms of temporomandibular joint disk displacement. Because it requires no radiation exposure and reproduces soft tissue in good detail, it far outranks other imaging procedures for this purpose. The ability to depict bone structure, too, has been greatly improved and its reproduction of detail ranks only slightly below that of CT (Westesson et al. 1993). Cerebral aneurism clips, heart pacemakers, and ferromagnetic foreign bodies are *contraindications* to its use, but orthodontic appliances, dental implants, and dental restorations are not.

411 MR parameters for routine examination of the temporomandibular joints

The figures given are for the MRT machine by Elscint with 0.5 and 2.0 teslas.

TR Repetition time
TE Echo time
TA Tilt angle
Sl.Th. Slice thickness
FOV Field of view
NEX Number of repetitions
* Closed and open
Open
SE Spin echo
FSE Fast spin echo

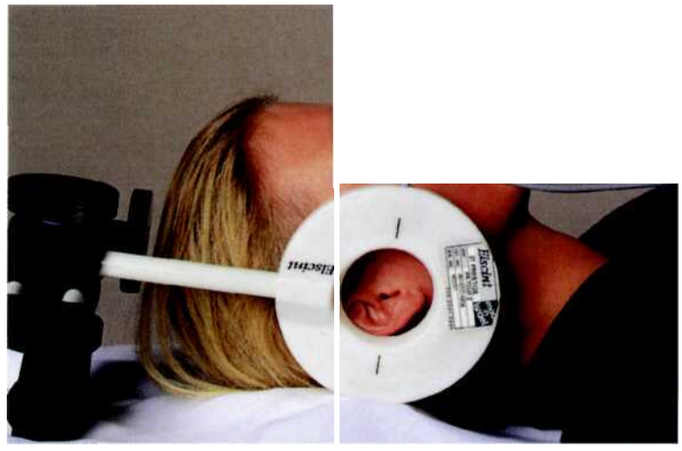
O.5 Tesla	Sequence	TR	TE	TA	SD*	Matrix	FOV	NEX
T1 sag*	SE	450	25	90	3	256x256	14x14	2
T1 cor	SE	450	25	90	3	256x256	14x14	2
T2 sag**	Flash 2D	339	18	29	4	190x200	17x14	4
2 Tesla	Sequence	TR	TE	TA	SD	Matrix	FOV	NEX
T1 sag*	SE	400	20	160	3	346x316	14x14	2
T1 cor	SE	400	20	160	3	346x316	14x14	2
T2 sag**	FSE(ETL10)	2400	90	160	3	256x250	14x14	3
FSE	FSE(ETL4)	1200	18	150	3	256x256	14x14	3

412 MR tomograph

Modern units use either a closed or open system. In the widely used closed systems the patient lies in a tube within which a static magnetic field uniformly aligns the protons of the tissue to be studied. Switching off a dynamic radio frequency field causes the protons to revert to their original energy state. The electromagnetic energy this releases is received by special surface coils.

413 Patient position with a unilateral temporomandibular joint coil

The temporomandibular joint has a relatively low number of protons and therefore is a weak signal emitter. Therefore it requires a sensitive surface coil to produce an optimal image. Without this, it is impossible to produce an MR image that will provide sufficient information to be useful in treatment planning. The diameter of the coil should be 4-8 cm. Besides unilateral coils, there are also bilateral ones with which both joints can be recorded at the same time.



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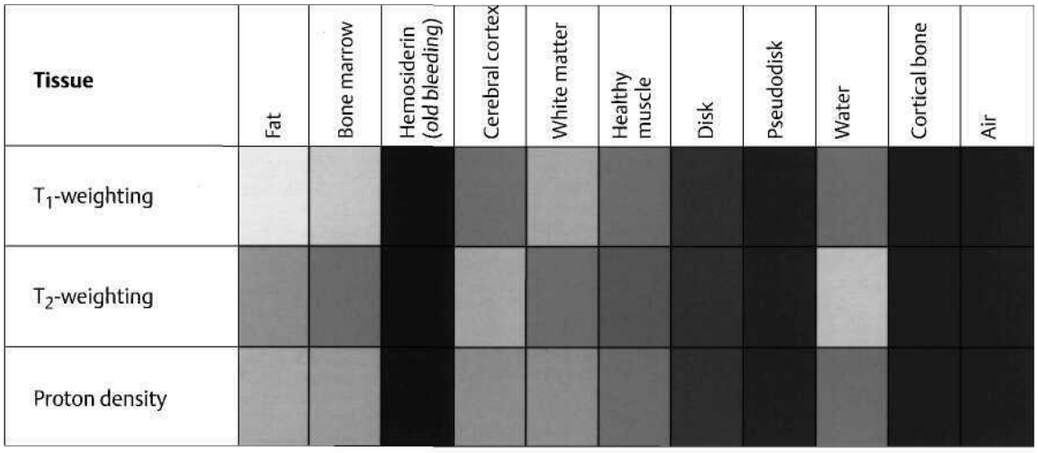
T1- and T2-Weighting

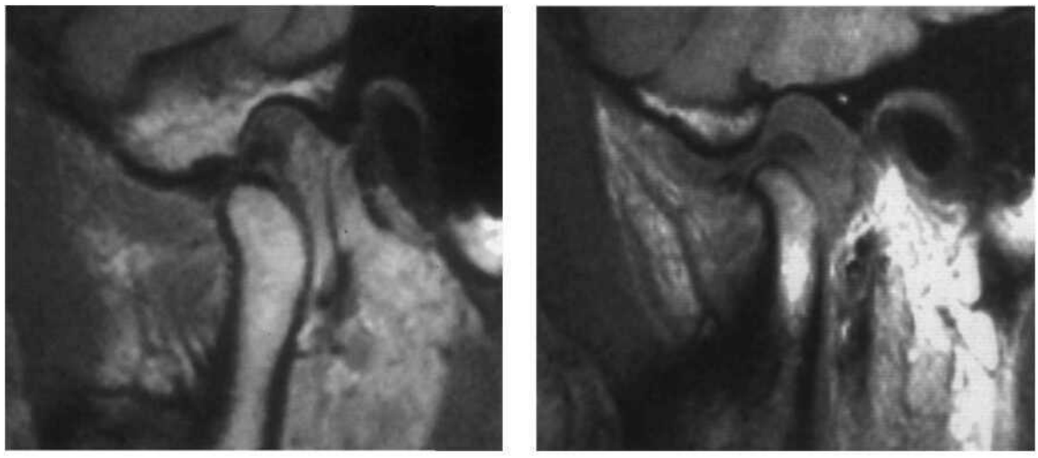
The magnetizing vector in the tissue is rotated 90° in the by plane by means of a high frequency (HF) impulse. At the end of the HF impulse, the protons relax back to their original energy level. The relaxation times T1 (spin lattice relaxation time) and T2 (spin-spin relaxation time) describe the change in magnetization in the z coordinate and the xy plane (Christiansen and Thompson 1990).

The smaller the T1 value of a tissue, the stronger its signal and the lighter the resulting image. Conversely, if the T1 value is large the image will be dark. Tissues with a large T2 value give a strong signal and light image and tissues with a short T2 time produce a weak signal and dark image.

By selecting the appropriate parameters the radiologist can make MR images that show either more T1 or more T2 characteristics. *T1-weighted* images are produced by using a short repetition time (TR <900-600 ms) and a short echo time (TE <20 ms). A *T2-weighted* MR image, on the other hand, is produced with a long repetition time (TR approximately 2000 ms) and a long echo time (TE approximately 80-120 ms) (Palacios et al. 1990).

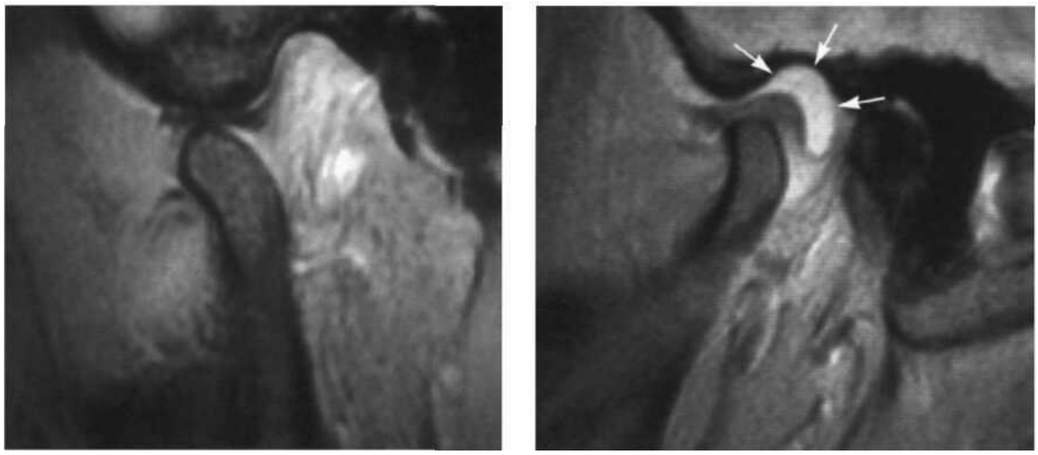


414 Signal intensity of different tissues in T1 - and T2-weighted MRIs
According to the signal intensity and the examination sequence, different types of tissue produce different values of gray. The shades of gray shown here correspond closely with those of the tissues in an actual MR tomogram.



415 T1-weighted MRI
Left: Normal temporomandibular joint. The T1-weighted image is especially suited for providing excellent demarcation of the anatomical structures with optimal topographic resolution.

Right: Joint effusion. Although the anatomical structures can be clearly identified, the T1-weighted image shown here gives no indication of the intra-articular fluid.



416 T2-weighted MRI
Left Normal temporomandibular joint. Here the topographic resolution is less than in a T1-weighted image, but the individual structures are still recognizable.

Right: The same joint as shown above. Now the joint fluid (arrows) can be clearly seen.
T2-weighted sequences are especially suited for identification of infections, edemas, and joint efussion and are therefore indicated as a basic procedure.

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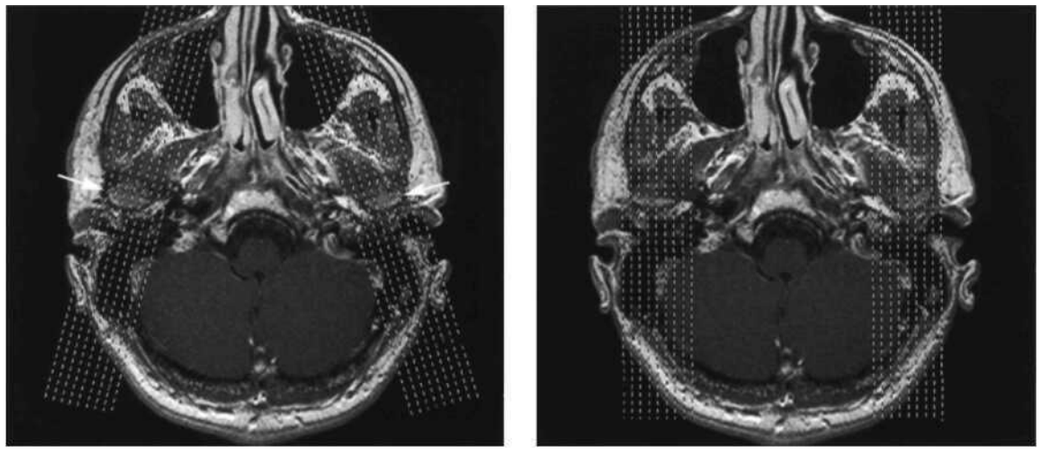
Selecting the Slice Orientation

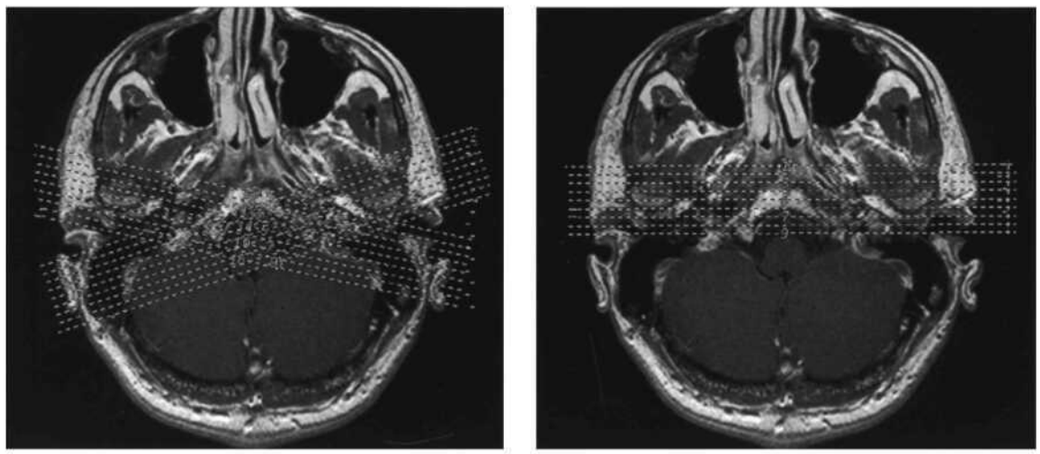
Basically, MR images can be oriented to three planes: sagittal, frontal, and transverse (horizontal). In clinical radiology the frontal plane is also referred to as the coronal plane, and the transverse plane is called the axial plane. An image showing the temporomandibular joints in the axial plane is used not only for diagnostic purposes, but also for planning the sagittal slices. Sagittal exposures can be made as either paramedian slices or angled sagittal slices (Yang et al. 1992). Images made in a paramedian plane have two clinical advantages: First, in images made with the jaws closed and open, the two slices are exactly comparable. Secondly, artifacts caused by orthodontic bands or extensive fillings in the posterior teeth will be less than in angled slices because the rows of teeth do not lie in the plane of the slice.

For imaging the temporomandibular joint in the frontal (coronal) plane, the slice can be made in a pure frontal plane or at a small lateral angle. For the past 10 years we have been using *angled slices in the frontal plane.* The angulation is planned so that each slice is parallel with the long axis of one or the other condyle and perpendicular to the long axis of the disk. This method reduces the partial volume effect (Steenks et al. 1994, Chen et al. 1997).

417 Slice alignment for sagittal images
For an MRI examination of the temporomandibular joint the first step is to make a horizontal orientation slice. In this plane the exact angulation of the condyles (arrows) can be determined. Basically, the sagittal slices can be made angled *(left)* or parallel with the median plane *(right).* Paramedian slices exhibit fewer of the artifacts caused by metal restorations in the dental arch. Furthermore, open-jaw and closed-jaw images will show the same parts of the joint in the same slice.



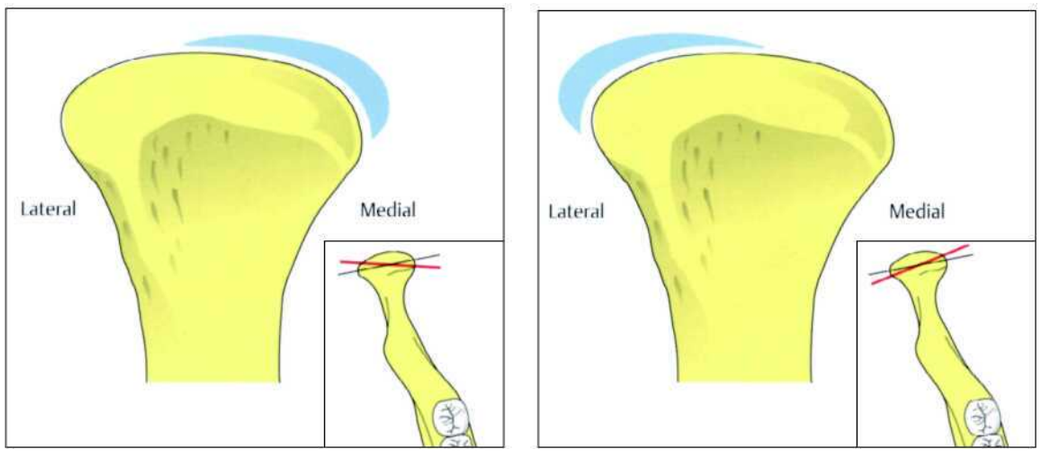
418 Slice orientation for frontal images
Frequently the radiologist will chose a frontal plane (right) to capture images of both joints at the same time and thereby simplify the MRI examination. However, this can result in significant errors in evaluating the disk-condyle relation because of the angulation of the condyles. Therefore, it is essential that each frontal slice be oriented parallel with the long axis of one of the condyles. This requires a separate examination for each joint.



419 Results of incorrect slice alignment in the frontal projection (right joint)
In the inserts the long axis of the condyle is indicated by the black line.

Left: Too much of a posterior angulation in the lateral region (red line) will make it appear that there is a medial disk displacement even when the disk-condyle relationship is normal.

Right: Excessive posterior angulation in the medial part of a normal joint will cause the MRI to mimic a lateral displacement of the disk.



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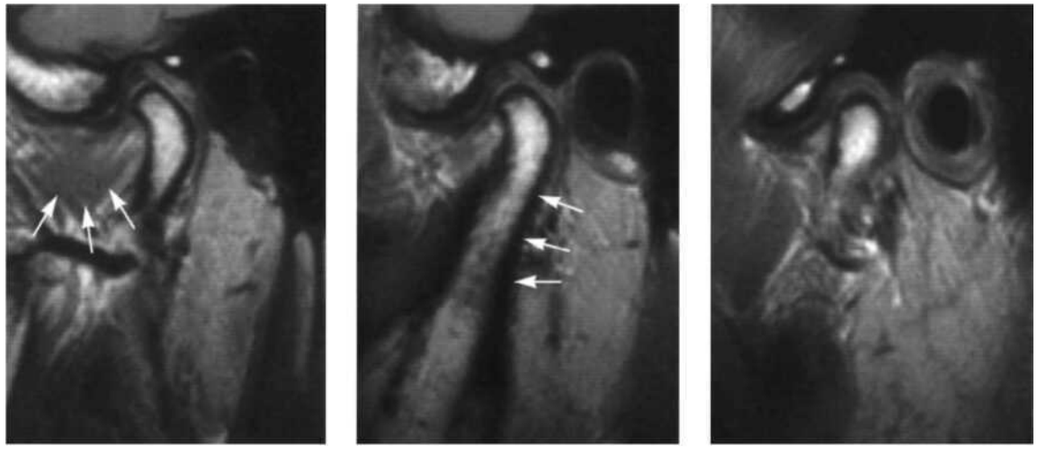
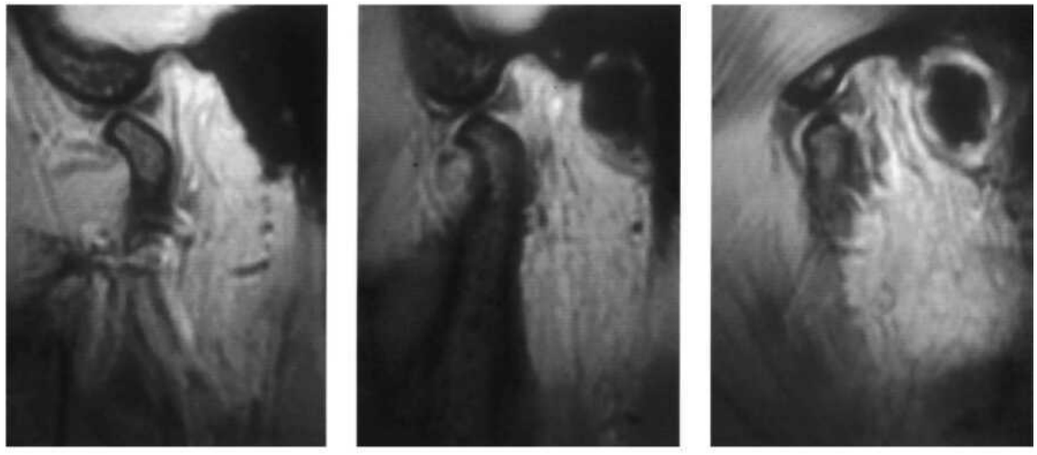
Practical Application of MRI Sections

For an examination of the temporomandibular joint the practitioner does not need all the MRI slices that have been prepared and stored in the computer. Three layers—a lateral, central, and medial—for each mandibular position are completely adequate. One should be able to make an unequivocal evaluation of the fossa, disk, and condyle on each slice. In addition to the Tl-weighted scan in habitual occlusion and the T2-weighted scan at maximum jaw opening, a T1-weighted scan in the prospective therapeutic mandibular position should always be made if there is a suspected disk displacement with repositioning.

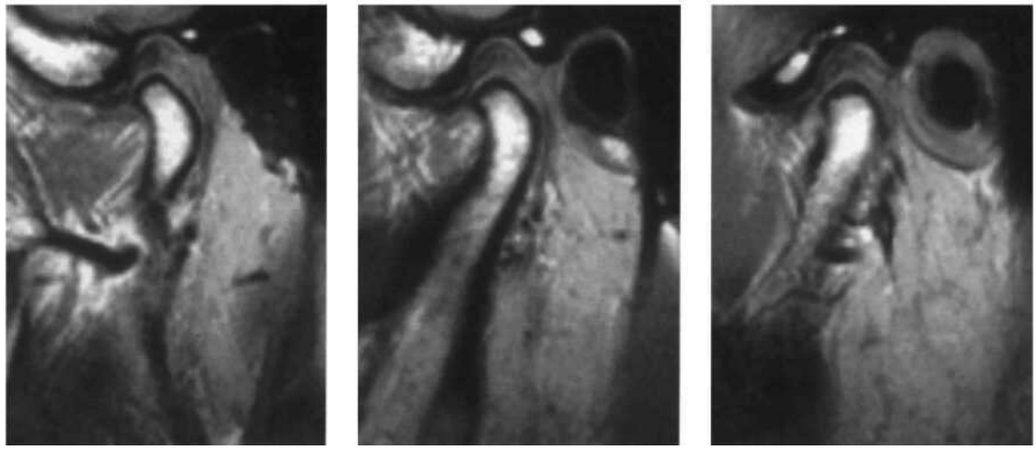
In the past, the *therapeutic disk position* was determined through clinical measures alone (Owen 1984, Davies and Gray 1997a-c) or with the help of electronic axiography. According to recent studies (Kircos et al. 1987, Katzberg et al. 1996), joints that are free of clicking sounds do not necessarily have a normal disk position. Therefore an image of the "therapeutic" disk-condyle relation is important for planning the treatment. The importance of this procedure is directly proportional to the complexity of the definitive occlusal stabilization that will be required after disk repositioning.



420 Habitual occlusion
MRI exposures at habitual occlusion are always made in a T1-weighting with the so-called spin-echo (SE) technique. The radiologist usually exposes six to eight slices, although images of only three layers (medial, central, and lateral) are necessary to adequately evaluate the disk-condyle relationship (Crowley et al. 1996). In a medial slice the lateral pterygoid muscle (arrows) can be identified. In the central slice (center) the posterior border of the ascending ramus (arrows) is always visible.



421 Maximal jaw opening
The second obligatory joint series is made at maximal jaw opening in T2-weighting. The T2-weighting is well suited to reveal inflammatory reactions and joint effusions (Larheim 1995). The combination of exposures (T1 closed and T2 open) makes it possible to avoid a complete MRI series with both weightings. Again, a lateral, central, and medial slice are made. If the maximal jaw opening is not secure, false positive findings are likely to be made (Watt-Smith et al. 1993).



422 Therapeutic occlusion
The most important sequence of the MRI examination is the depiction of the positional relationships of the fossa, disk, and condyle in the treatment position of the mandible. The prognosis of a conservative repositioning treatment depends to a large extent upon this view. To demonstrate a complete repositioning, medial, central, and lateral slices must again be made. When there is disk displacement without repositioning, this view is not as suitable as one in an angled coronal plane.

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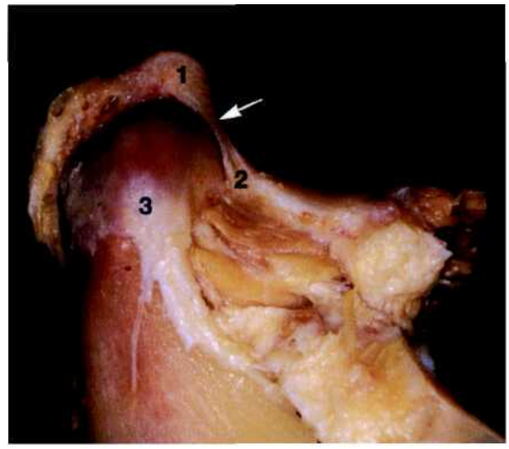
Reproduction of Anatomical Detail in MRI

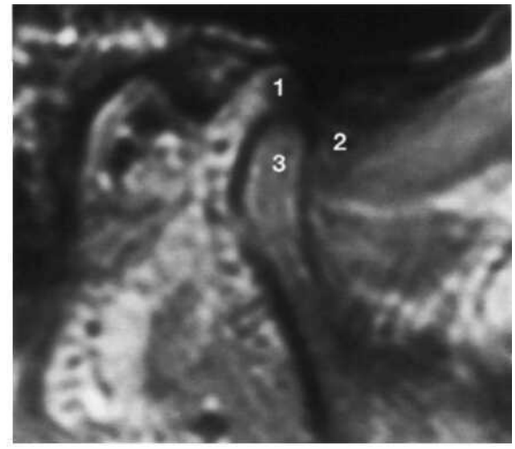
MRI is a reliable method for diagnosing disk abnormalities (van der Kuijl et al. 1992). Comparisons between MRI findings and observations during surgery showed a sensitivity of 0.86-0.98, a specificity of 0.87-1.00, a positive predictive value of 0.89-1.00, and a negative predictive value of 0.78-0.89 regarding correct identification of the disk position (Westesson et al. 1987, Bell et al. 1992, Tasaki and Westesson 1993). Furthermore, there is a high intraobserver agreement (95%) and interobserver agreement (91%) (Tasaki et al. 1993).

Differentiation of the retrodiskal tissue from the pars posterior is possible by systematic use of T1- and T2-weighted scans (Crowley et al. 1996). Thus MRI represents the gold standard for imaging soft tissue and determining the disk position within the temporomandibular joint (Kamelchuk et al. 1997). In spite of concerns from theoretical studies (Masumi et al. 1993, Fellner et al. 1997), artifacts caused by orthodontic appliances do not present a clinically significant problem in imaging the temporomandibular joint if paramedian slices are used (New et al. 1983, Sadowsky et al. 1988).

423 Normal joint
Left: Macroscopic anatomical preparation of a right temporomandibular joint with normal disk position. The pars posterior (1), pars anterior (2), pars media (arrow), and condyle (3) can be clearly seen.

Right: In spite of the reduction in signal caused by formalin fixation, the corresponding slice in MRI shows the identical relationships between the disk (1,2) and condyle (3).

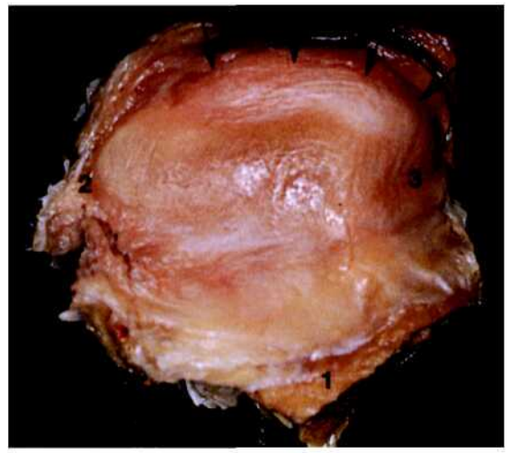


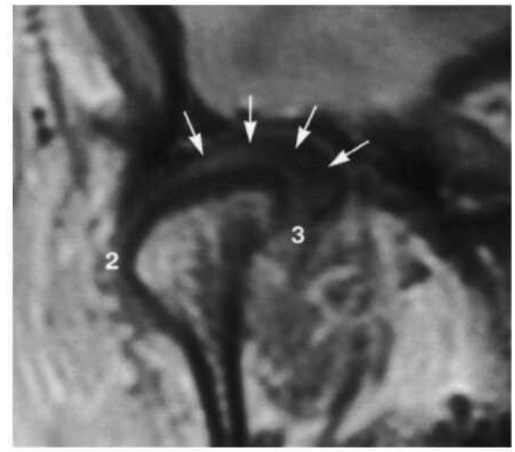


424 Medial disk displacement
Left: Formalin-fixed preparation from a right joint. In this anterosuperior view, the displacement of the disk (arrows) toward the medial is evident.

1 Lateral pterygoid muscle
2 Lateral pole
3 Medial pole

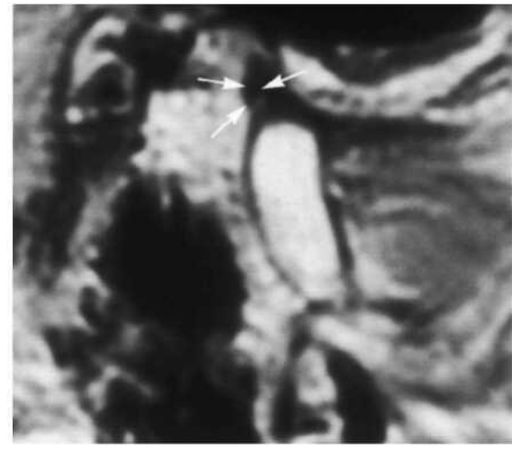
Right: MRI in the angled coronal plane confirms the medial disk position (arrows). The contours of the fossa and condyle are reproduced precisely.





425 Shape of the pars posterior
Left: Macroscopic anatomical preparation of a right articular disk showing its positional relationship to the condyle. The posteroinferior edge of the pars posterior (1) shows a small triangular area of fibrosis (arrows).

Right: In spite of the sharply reduced signal emission resulting from formalin fixation, even this type of change is accurately reproduced (arrows). Here the use of a combination of TI and T2 weighting is often helpful.



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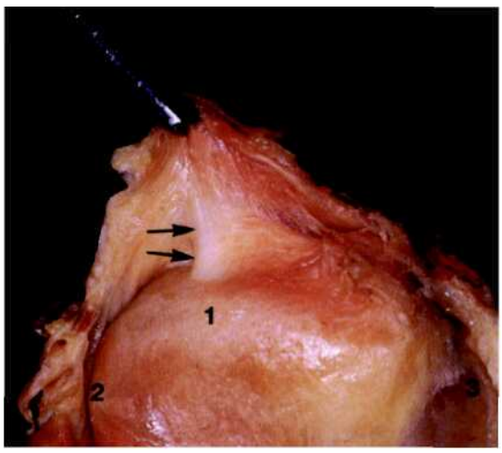
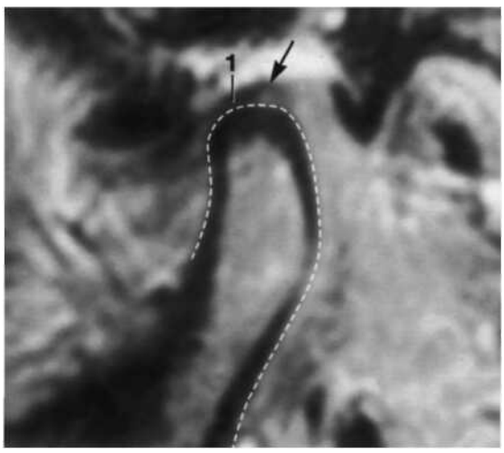


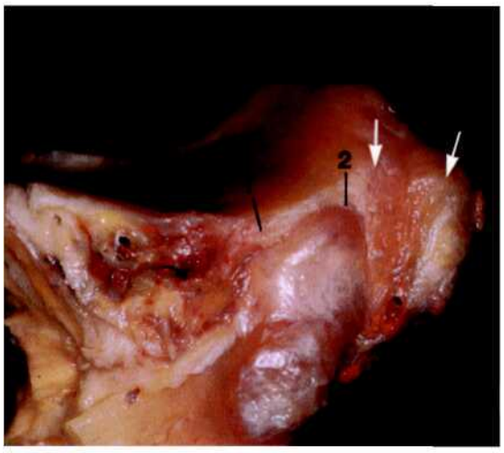


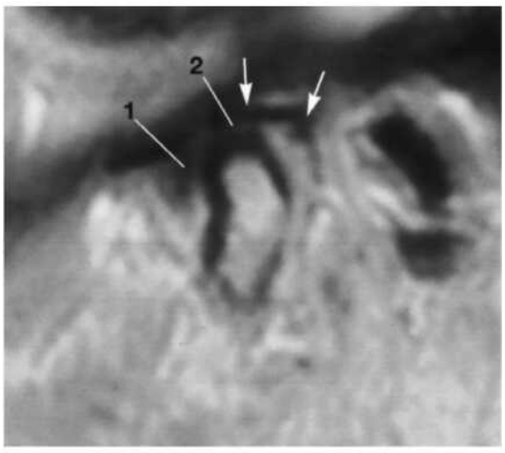
426 Fibrosis of the bilaminar zone

Left Formalin-fixed preparation of the centromedial part of a left temporomandibular joint with localized fibrosis of the bilaminar zone (arrows).

1 Pars posterior
2 Medial pole
3 Lateral pole

Right: The MRI accurately reproduces the abnormality (arrows) distal to the flattened pars posterior. The contour of the condyle is indicated by a broken line.

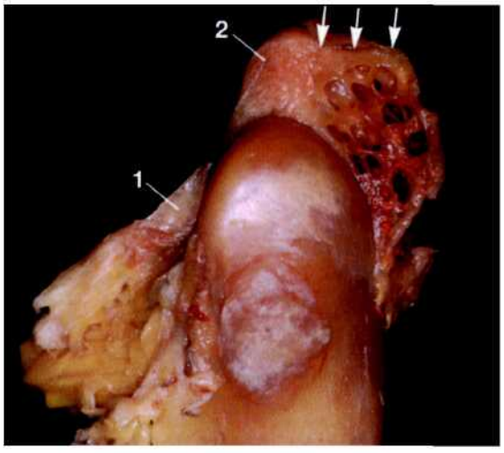


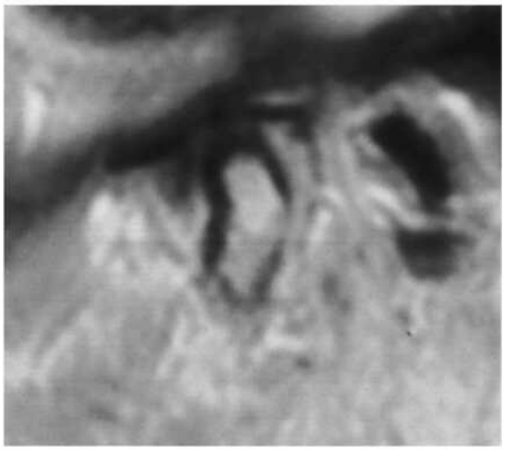


427 Presumed "posterior disk displacement"

Left: Macroscopic preparation of a left temporomandibular joint with normal positioning of the pars anterior (1) and pars posterior (2) in the lateral portion of the joint. The retrodiskal structures appear thickened.

Right: In an MRI there appears at first glance to be a posterior disk displacement (arrows). Under closer inspection, however, it can be seen that the pars anterior (1) and pars posterior (2) lie in correct relation to the condyle.

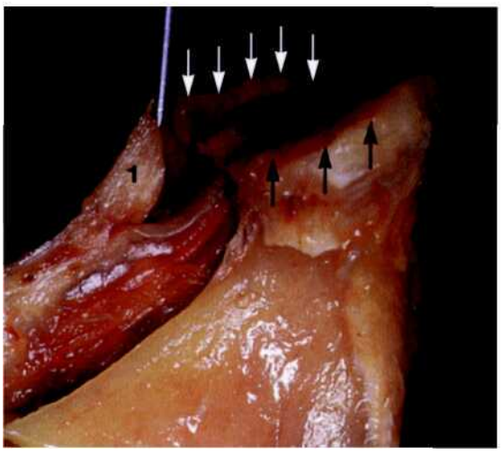


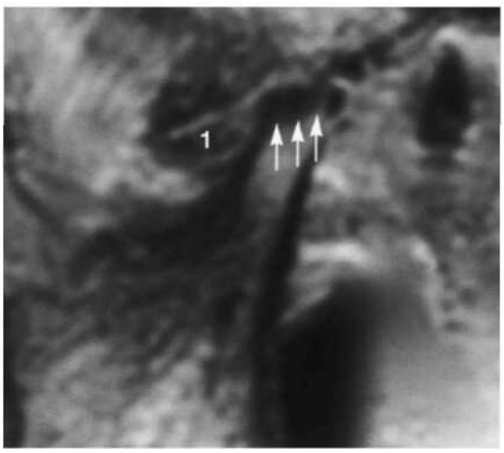


428 Presumed "posterior disk displacement"

Left: A view of the disk and the bilaminar zone after further preparation again reveals the correct positional relationships. Here the pars anterior (1) and pars posterior (2) can be identified more readily. The presumed "posterior disk displacement" is a false positive interpretation of the fibrosis of the bilaminar zone (arrows).

Right MRI of the same joint shown in Figure 427.





429 Disk perforation and osteoarthrosis

Left Anatomical preparation of a left temporomandibular joint with arthrotic changes (black arrows) and extensive disk perforation (white arrows). In the anterior region only a part of the former pars anterior (1) can still be recognized.

Right MRI shows similar conditions. The cortical layer of the arthrotic condyle is thickened extensively (arrows). The remainder of the pars anterior (1) can still be distinguished.

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Visual (Qualitative) Evaluation of an MR Image

The most common method for evaluating an MR image is visual inspection. The form reproduced below is used for systematically recording the findings and is based on parameters that are strictly treatment oriented. Other characteristics have been described for evaluation (Drace and Enzmann 1990, Kordaß et al. 1990, Bumann et al. 1996, Rammelsberg et al. 1997), but these have not been demonstrated to be relevant to treatment.

A treatment-oriented MRI evaluation is based upon joint scans made with the teeth in habitual occlusion, with the jaws maximally opened and, if there is disk displacement with repositioning, with the teeth in the treatment occlusion or, if there is disk displacement without repositioning, in an angled coronal (frontal) plane with the jaws closed. The degree of disk displacement is determined in three sagittal slices for each joint. Other conditions evaluated by MRI are the exact extent of disk repositioning, the shape of the pars posterior as a stabilizing element after repositioning, adaptation (fibrosis) of the bilaminar zone, deformations of the fossa and condyle, displacement of the condyle, and disk displacement in the coronal plane.

430 Visual MRI analysis
The record form for visual analysis of MR images contains all the parameters relevant to treatment, encompassing changes in the fossa, condyle, disk, and bilaminar zone. Each individual parameter and the findings related to it will be described in detail on the pages that follow.
A compilation of these findings from the medial, central, and lateral portions of the joint provides a "three-dimensional" description of the disk and its relation to the condyle.
The various tissue-specific diagnoses are listed in the lower right section of the form.
DD = disk displacement

Patient		Bumann's visual MRI analysis			
		Date	Closed	Open Closed in therapeutic position	Frontal
		R			
		L			
	DD closed	DD open	DD with registration	Pars posterior: Closed / Open	Adaptation of bilaminar zone
	R L	R L	R L	R L / R L	R L
Lateral					
Central					
Medial					
	1 none 2 insidious 3 definite 4 n.a.	1 none 2 insidious 3 definite 4 n.a.	1 none 2 insidious 3 definite 4 n.a.	1 biconvex 2 biplanar 3 wedge-shaped 4 n. a.	1 present 2 not present 3 n. a.
	Adaptation condyle and fossa	Condylar displacement	Remarks		
	R L	R L			
Lateral					
Central					
Medial					
	Stage 0 Stage Stage II Stage III	1 none 2 anterior 3 posterior 4 superior 5 inferior 6 n. a.			
DD frontal	Diagnosis		Codes for recording the diagnoses		
R L	R	L	0 No pathological findings 1 Disk adhesion 2 Disk hypermobility 3 Partial DD with total repositioning 4 Partial DD with partial repositioning 5 Partial DD without repositioning 6 Total DD with total repositioning 7 Total DD with partial repositioning 8 Total DD without repositioning 9 Ada	10 Joint effusion 11 "Deviation in form" 12 Osteoarthrosis 13 Condyle displacement 14 Condyle hypermobility	
1 none 2 medial 3 lateral 4 n. a.					

Station Of the bilaminar Zone Copyright by Axel Bumann. Boston 1998

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Classification of the Stages of Bony Changes

Classification of bony changes in the temporomandibular joint usually has no therapeutic relevance, but serves only for documentation of the initial conditions and for legal protection. There are, however, two special circumstances that do have therapeutic consequences:

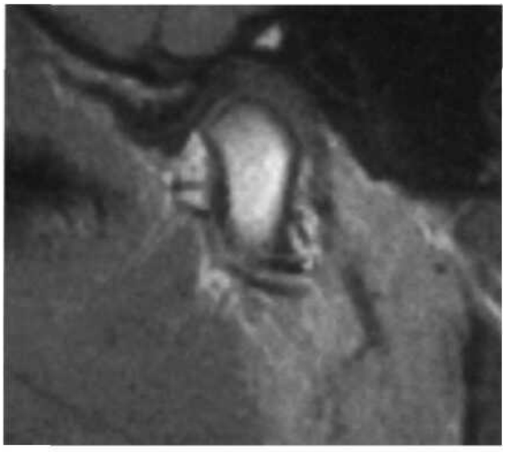
- Evidence of regressive adaption on the fossa, articular eminence, or condyle associated with pain upon dynamic compression frequently requires treatment with anti-inflammatory drugs.
- The more pronounced the appearance of regressive adaptation on the bony joint surfaces, the poorer the long-term prognosis for conservative treatment to reposition displaced disks.

We use the classification system of Anderson (1996) that distinguishes four stages of progressive and regressive changes in the fossa and on the condyle. Stages 0 and I are best diagnosed using T1-weighting and stages II and III using T2-weighting. In MRI analysis there are two *pathological signal patterns* that can be differentiated (Lieberman et al. 1996):

- Sclerosis (T1 and T2 hypointense)
- Bone marrow edema (T1 hypointense, T2 hyperintense).

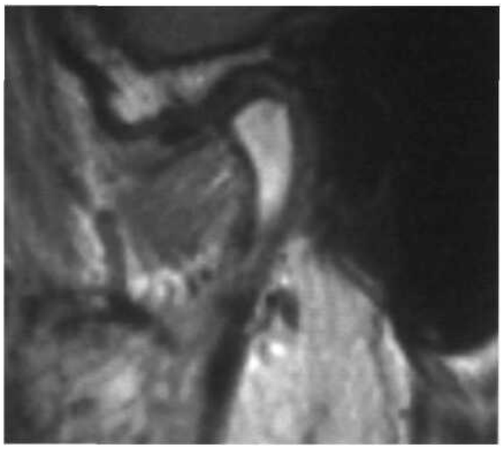
	Condyle		Fossa	
	Form	Bone density	Form	Bone density
Stage 0	Convex	Normal	Convex	Normal
Stage 1	Slight deformation	Slight sclerosis	Slight deformation	Slight sclerosis
Stage II	Mild to moderate	Mild to moderate	Mild to moderate	Mild to moderate
Stage III	Severe deformation	Severe sclerosis	Severe deformation	Severe sclerosis

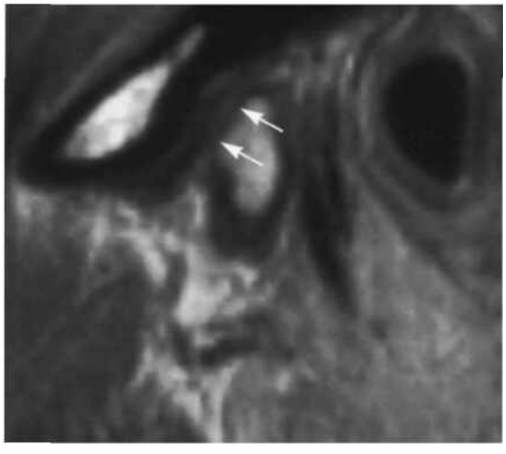
431 Stages of bone degeneration
Degenerative changes in the bone of the condyle, fossa, and articular eminence can be divided into four stages. The bony structures should always be evaluated with a T1-weighted scan made with the jaws closed and a T2-weighted scan at maximum jaw opening. Documentation is made of the worst stage found at the time. As a rule, the extent of bony changes is independent of the disk position.



432 Stages 0 and I
Left: MRI of a left temporomandibular joint in stage 0. The contours of the fossa and condyle are smooth. The bone density in the condyle is normal.

Right: MRI of a left temporomandibular joint with stage I degenerative changes. The anterior part of the condyle is slightly flattened. The articular protuberance shows slight irregularities and an increased level of sclerosing. No treatment decisions can be made from these findings, however.





433 Stages II and III
Left: Typical appearance of a left temporomandibular joint in stage II. The condyle is obviously more flattened and sclerosed. Evaluation of 831 MR images gave the following distribution: 17% stage 0, 58% stage I, 19% stage II, and 6% stage III (Bumann et al. 1999).

Right: MRI of a stage IV joint. The deformation of the condyle is quite advanced (arrows). There is a significantly higher incidence of changes in the lower joint space than in the upper (Kondoh et al. 1998).

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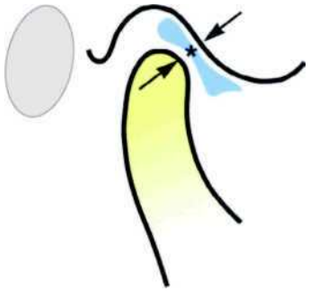
Disk Position in the Sagittal Plane

The disk position with the teeth in habitual occlusion is one of the most important parameters in visual MRI analysis. In the physiological position the disk lies with its pars intermedia in the region of the closest distance between the anterosuperior curvature of the condyle and the articular protuberance. From this position there can be a *direct* or *definite* displacement. If the posterior border of the pars posterior lies in front of a line representing the shortest distance between the condyle and the protuberance there is definite disk displacement. With this condyle-disk relation there will always be a clicking sound insofar as the disk can reposition itself during jaw opening. As long as one part of the pars posterior still lies on the condyle, it is referred to as an *insidious disk displacement* or a *tendency to disk displacement.* A separate classification of disk position is made for each of the three joint sections (medial, central, and lateral).

The physiological disk position varies with the inclination of the condylar path, and therefore other methods of defining the disk position, such as those presented by Katzberg (1989) and Dace and Enzmann (1990) are not suitable for clinical purposes.

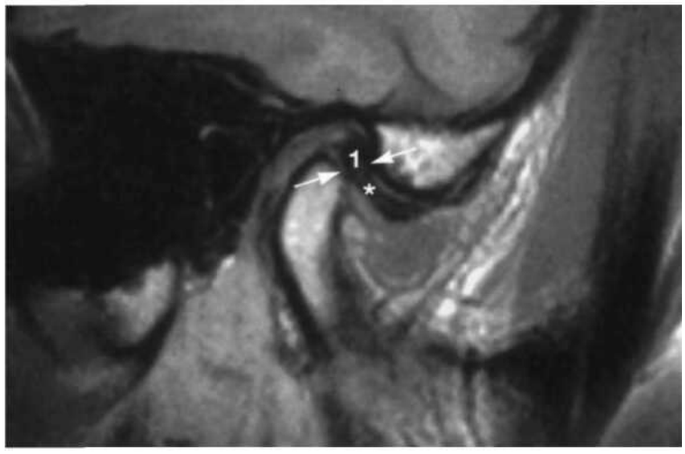
434 Physiological disk position
Under normal conditions, the pars intermedia (*) of the disk lies between the anterosuperior curvature of the condyle and the articular protuberance (arrows). The position of the posterior border of the pars posterior relative to the vertex of the condyle varies according to the inclination of the protuberance and is therefore not a reliable parameter.

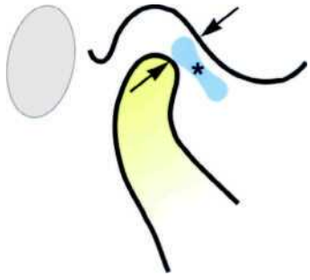
The arrows in this schematic drawing mark the relative positions of the condyle and the pars intermedia to one another.



435 Insidious disk displacement or a tendency to anterior disk displacement
The pars intermedia (*) lies well in front of the shortest distance between condyle and protuberance (arrows), but the pars posterior (1) still lies on the condyle. Clinically, there are no clicking sounds during jaw opening.

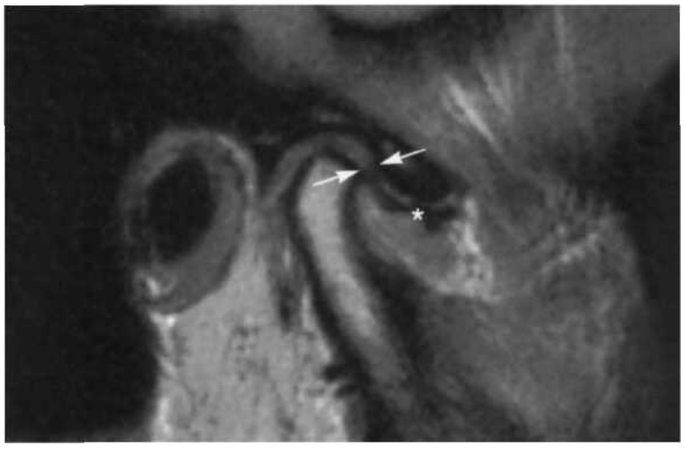
Right: Drawing of a joint with a tendency to anterior disk displacement. The arrows mark the discrepancy between pars intermedia and condyle.

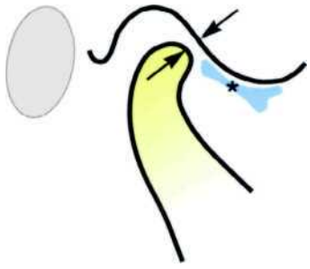




436 Definite disk displacement
Left: Both the pars intermedia (*) and the posterior border of the pars posterior lie in front of the most anterosuperior curvature of the condyle (arrows). Unless this is a case of disk displacement without repositioning, a clicking sound will occur regularly during jaw opening.

Right: Schematic drawing of a definite anterior disk displacement. The arrows mark the discrepancy between the pars intermedia and condyle.





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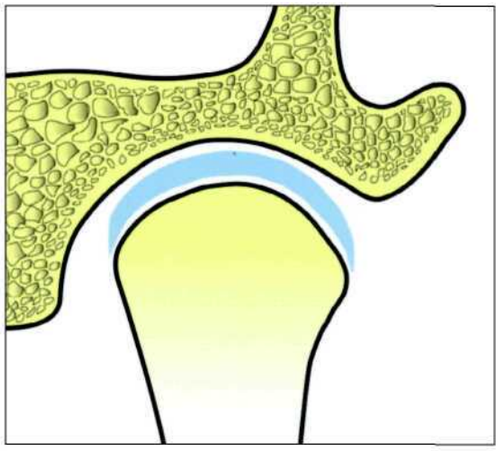
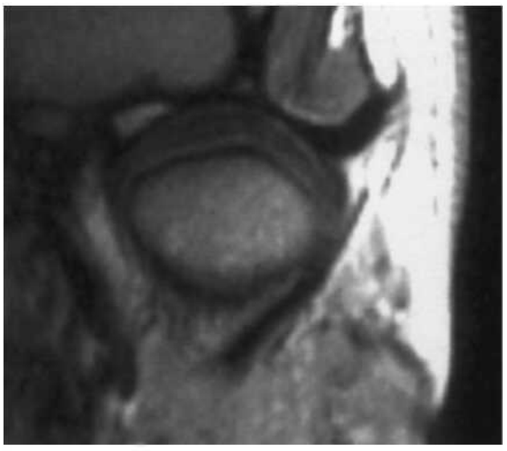
Disk Position in the Frontal Plane

The lateral and medial portions of the joint are evaluated in an MR image made in the frontal plane with the jaws *dosed* (Brooks and Westesson 1993). Angling the frontal plane so that it is parallel with the long axis of the targeted condyle will improve the quality of the image (Westesson 1993). The position of the disk should be determined by using a slice through the pars posterior because the other parts of the disk cannot be as well depicted due to their thinness. When healthy subjects were studied, 1.8% were found to have disks displaced laterally, and 0.9% medially. Among temporomandibular joint patients the incidence rose to 4.5% for lateral and 4.1% for medial disk displacements (Tasaki and Westesson 1993). A macroscopic study of anatomical specimens found similar values (3% lateral, 5% medial; Christiansen and Thompson 1990). Incorrect angulation of the frontal plane can give a false picture of a lateral displacement (angulation too small) or medial displacement (angulation too large) of the disk and thereby lead to an incorrect interpretation and a different set of percentage figures (Khoury and Dolan 1986, Katzberg et al. 1988, Schwaighofer et al. 1990, Hugger et al. 1993).

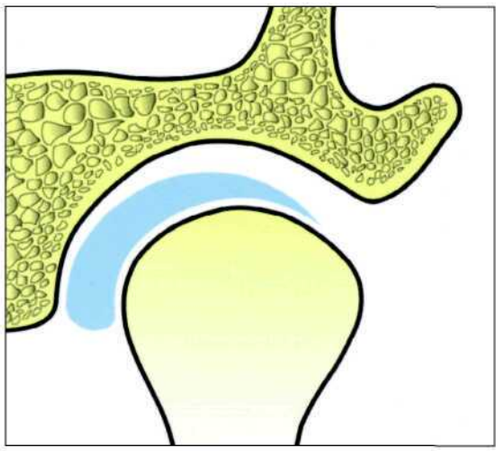


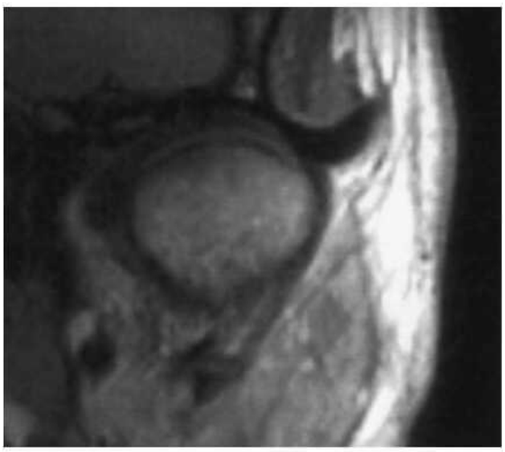


Disk position in the frontal plane

437 Physiological disk position
Left: Schematic drawing illustrating normal disk position in the frontal plane.

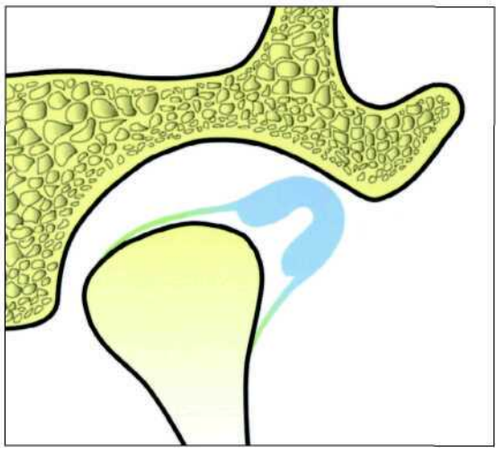
Right: MRI of the right temporomandibular joint of a 24-year-old man. The frontal plane is angled so that it is parallel with the long axis of the condyle. With the jaws closed, the pars posterior of the disk is centered over the condyle.

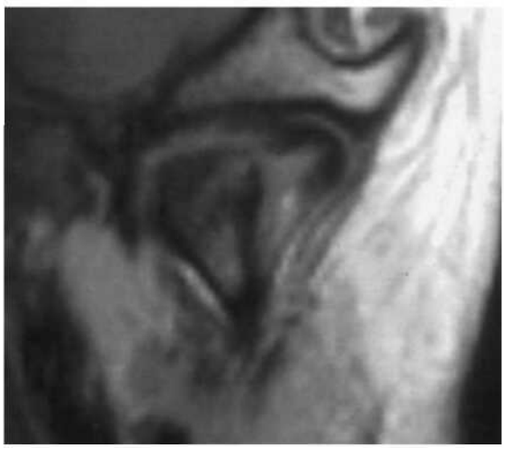




438 Medial disk displacement
Left Schematic drawing of a medial disk displacement in the frontal plane.

Right: MRI of the right temporomandibular joint of a 24-year-old patient. An adequate diagnosis of lateral and medial disk displacements cannot be made with arthrography and arthrotomography alone (Kurita et al. 1992a,b).





439 Lateral disk displacement
Left: Schematic drawing of a lateral disk displacement in the frontal plane.

Right: MRI of the right temporomandibular joint of a 23-year-old woman who sustained a fracture of the neck of the condyle at age 14 years. The condyle was tipped medially and has healed in an abnormal position. The lateral disk displacement is causing pain and recurring limitation of jaw opening.

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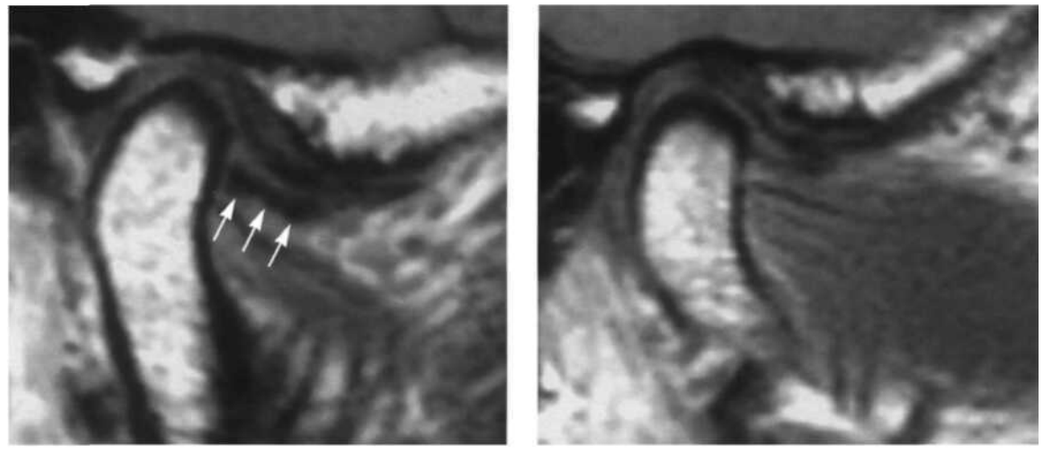
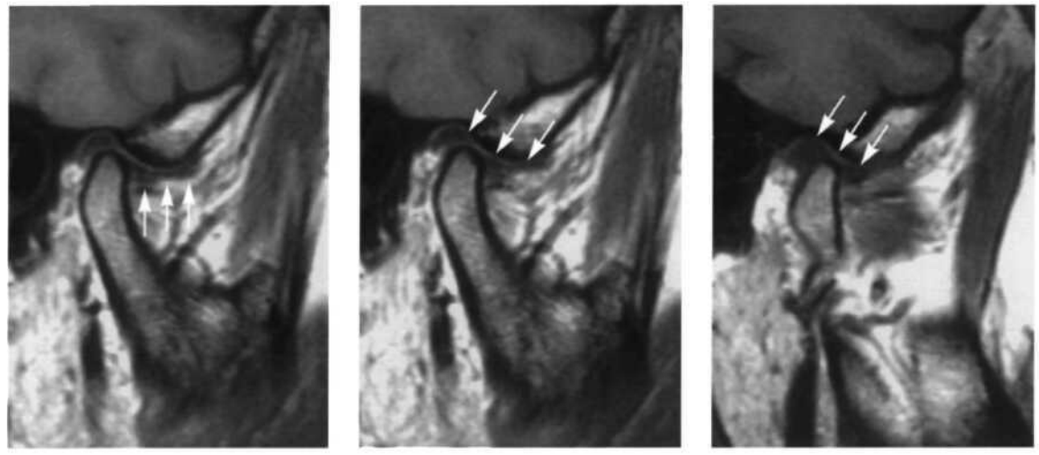
Misinterpretation of the Disk Position in the Sagittal Plane

Numerous studies have found an agreement rate of 80-95% between MR images and anatomical dissections of the temporomandibular joint regarding the disk position (Katzberg et al. 1988, Santler 1993, Tasaki and Westesson 1993). As described in earlier chapters of this book, the formation *of a pseudodisk through fibrosis of the bilaminar zone* is one possible cause of misinterpretations of MR images (Katzberg et al. 1986, Drace et al. 1990). Other factors that can cause false evaluations of the disk position are signal-poor sections of tendon in the superior head (Beltran 1990, Bumann et al. 1992a) or inferior head (Bittar et al. 1994) of the lateral pterygoid muscle. But also fibrosis, which reduces the signal intensity, in the anterosuperior part of the jont capsule can mimic an anterior disk displacement. The fundamental statement that "the imaging procedures must fit the clinical findings, and not vice versa" applies especially to an evaluation of the disk position in the temporomandibular joint. When findings disagree, inclusion of adjacent MRI slices in the analysis frequently resolves the question.



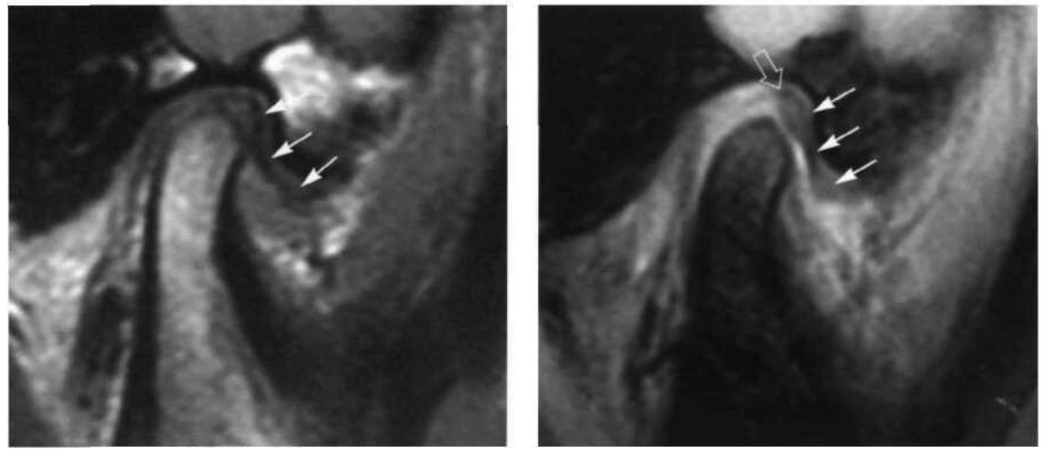
440 Tendon of the lateral pterygoid muscle
Left: In this MRI of a 45-year-old man, the weak signal from the tendon of the inferior head of the lateral pterygoid muscle creates an image (arrows) that could be misdiagnosed as "an anteriorly displaced biconcave disk." Upon closer inspection, however, the flattened disk can be seen lying between the condyle and articular eminence.
Right: This slice made 3 mm farther medially shows a tendency to anterior disk displacement with fibrosis of the bilaminar zone. In this section the signal-poor tendon can no longer be seen.



441 Fibrosis of the anterosuperior portion of the joint capsule
Left: Upon superficial inspection this MRI of a 48-year-old woman appears to show a complete anterior disk displacement (arrows). This appearance, however, is due to fibrosis of the upper anterior part of the joint capsule.

Center: A correct evaluation reveals that the disk is in its normal position on the condyle (arrows).

Right: This slice 3 mm farther medial confirms the finding of a normal disk position (arrows).



442 Specific examination sequences
Left: Left temporomandibular joint of a 15-year-old with a distinct tendency for anterior disk displacement (arrows; spin-echo [SE] technique)

Right: Superficial inspection of the same joint imaged with a gradient echo technique (Flash 2D) could lead one to assume that the disk position is normal. In the correct interpretation, the true boundaries of the disk (arrows) and the fibrosed bilaminar zone (outlined arrow) are lying behind the pars posterior.

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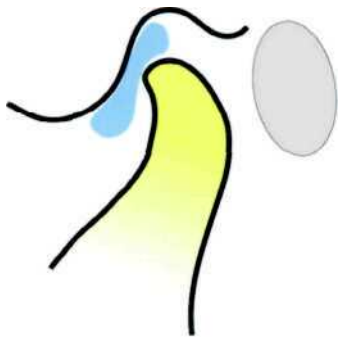
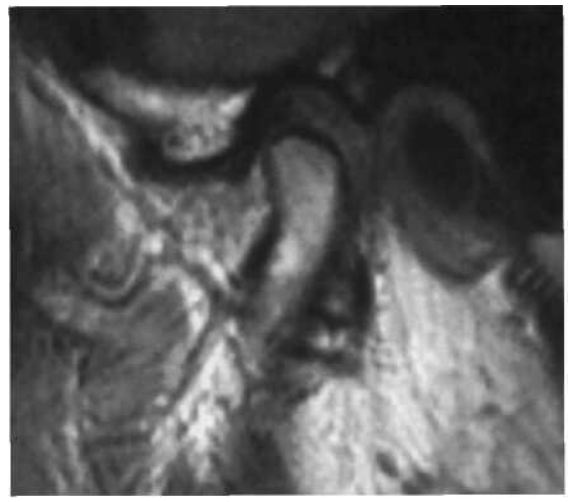
Morphology of the Pars Posterior

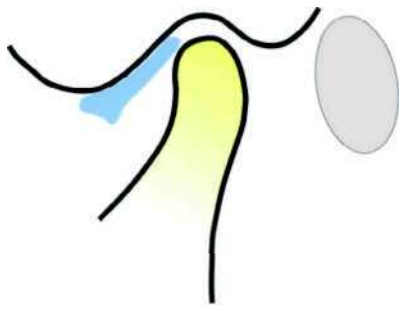
The morphology of the pars posterior (or posterior band) of the disk is especially important for the stability of the disk-condyle complex. The pars posterior has the highest resistance of all parts of the disk (Mills et al. 1994). It averages 2.6 mm in thickness (Bumann et al. 1999). In older patients the thickness of the disk always decreases significantly from medial to lateral, but the same is not true for the articulating cartilage of the condyle (Stratmann 1996). The resultant force of the muscles of mastication is normally directed anterosuperiorly against the articular protuberance in the joint (Chen and Xu 1994). Sustained superior or posterosuperior loads can lead to flattening of the primarily biconvex pars posterior (Osborn 1985). According to an evaluation of 1218 MR images, there are three forms of pars posterior that are clinically relevant (Bumann et al. 1999): *biconvex, biplanar,* and *flattened wedge-shape.* Flattening of the pars posterior by persistent improper loading of the temporomandibular joint occurs only when there are superior or posterosuperior loading vectors. Disk displacement can occur even without flattening of the pars posterior under purely posterior loading vectors.

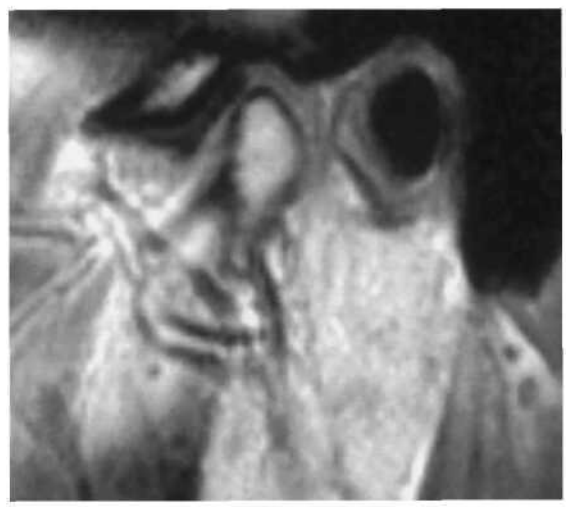




443 Normal pars posterior
Left Schematic drawing of a normal biconvex pars posterior.

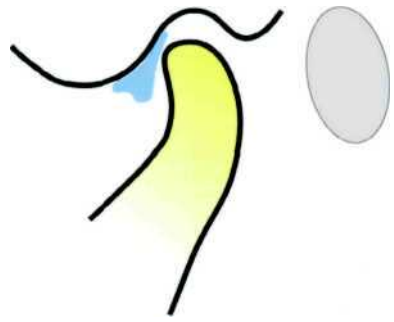
Right: MRI of a normally positioned disk with biconvex pars posterior. The pars posterior is thicker than the distance between the anterosuperior contours of the condyle and protuberance. This makes it difficult for the disk to become displaced anteriorly, and so it is stabilized on the condyle.

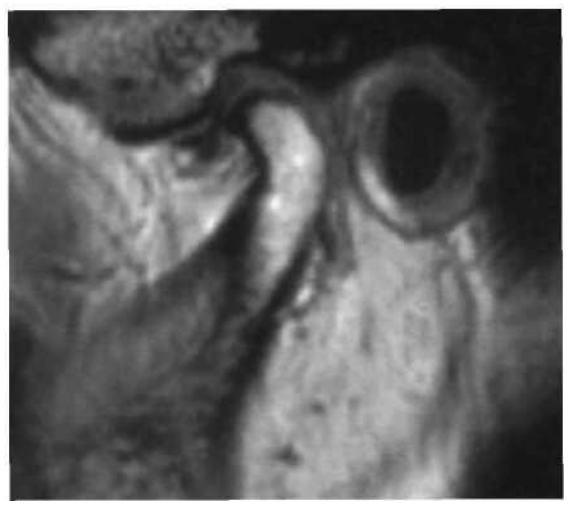




444 Biplanar flattening
Left: Schematic drawing showing nearly parallel superior and inferior surfaces of the pars posterior.

Right: The shape of the pars posterior can appear different in images made with the jaws open and closed. Therefore it should always be evaluated in images scanned in both jaw positions. With the jaws open, approximately 70% of the joints exhibit a biconvex pars posterior in at least one section.





445 Wedge-shaped flattened pars posterior
Left: Schematic drawing. This change in shape can be brought about only through persistent superior or posterosuperior loading vectors.

Right: Corresponding MR tomogram. Flattening of the pars posterior may or may not be accompanied by disk displacement. As the extent of anterior displacement increases, the percentage of disks that are flattened increases significantly (from 30% to 61%).

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Progressive Adaptation of the Bilaminar Zone

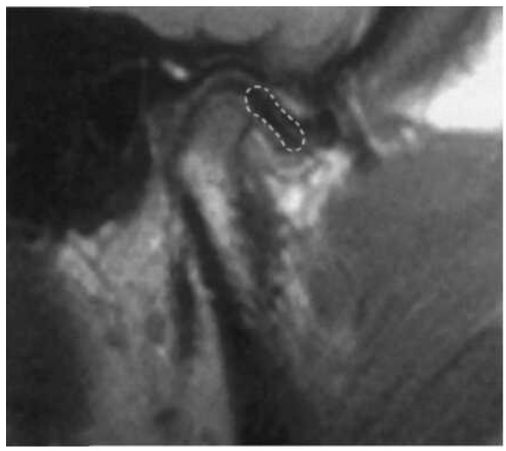
The dominant histological features of the bilaminar zone are fibroblasts, thick-walled arterioles, thin-walled veins, and numerous vascular sinuses (Wish-Baratz et al. 1993). In spite of the high level of glycosaminoglycans in the cartilage matrix, there are no chondrocytes in the normal joint. Loading of the bilaminar zone by posterosuperior or posterior loading vectors leads to either

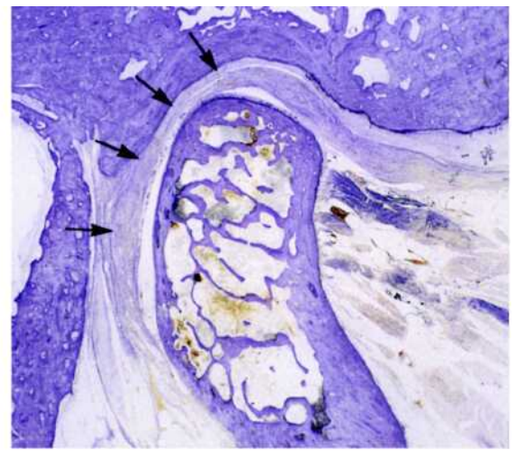
- stimulation of collagen synthesis = progressive adaptation, or
- inflammatory, painful changes = regressive adaptation.

Progressively adapted connective tissue is made more resistant to loading through the deposit of polyanionic glycosaminoglycan (Scapino 1983, Blaustein and Scapino 1986) and this gives rise to a so-called pseudodisk (Mongini 1995). Progressive adaptation of the bilaminar zone depends, not upon the disk position, but rather upon the direction and magnitude of the forces acting on the joint. Fibrosis can occur with a normal disk position as well as with disk displacements with or without repositioning. This is of great therapeutic significance, as more than 90% of joint pains arise from the bilaminar zone.

446 Progressive adaptation with formation of a pseudodisk
Left: MRI of a completely and progressively adapted bilaminar zone. The contours of the disk, which has a tendency for anterior displacement, are indicated by the broken line. Because of the flattening of the biplanar pars posterior and the optimal progressive adaptation in the bilaminar zone, there are no clicking sounds.

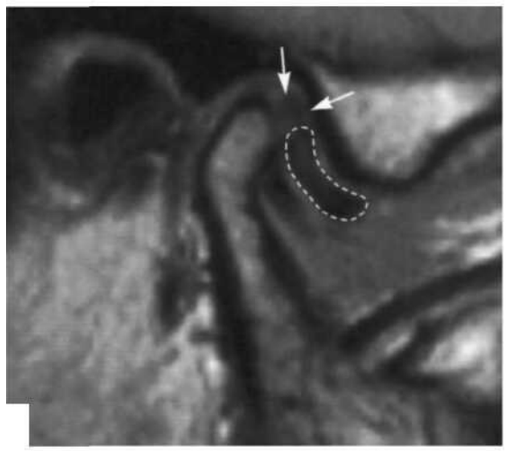
Right: Histological preparation showing obvious fibrosis of the bilaminar zone (arrows).

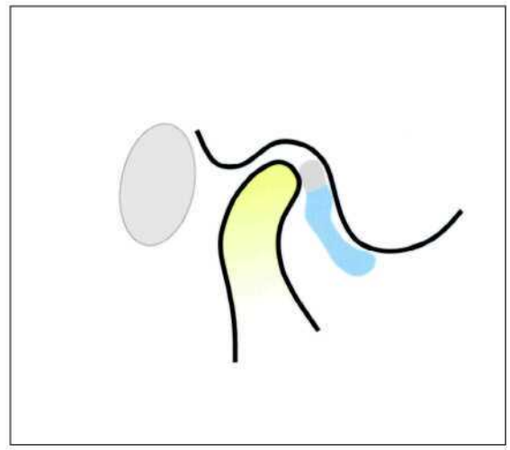




447 Localized progressive adaptation
Left: Obvious anterior disk displacement (broken line) with progressive adaptation (arrows) directly behind the pars posterior. Although from a morphological point of view the disk is clearly displaced anteriorly, the condition is described functionally as a "tendency for anterior disk displacement" because of the pronounced progressive adaptation. And so here too, there are no clinical clicking sounds as the patient opens his jaws.

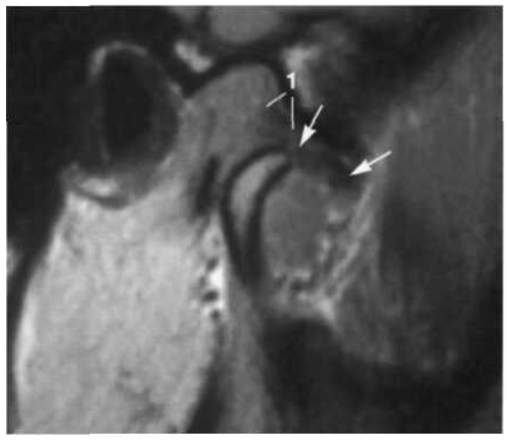
Right: Schematic drawing of the MRI findings.





448 "Presumed disk repositioning" in a case of progressive adaptation
Left: In this central slice made with the jaws open, the disk lies entirely anterior to the condyle (arrows). The adaptation of the bilaminar zone (1) could be mistaken for a repositioned disk.

Right: A slice made 3 mm lateral to the first confirms that there is disk displacement without repositioning (arrows). Both images show an identical disk position with differing degrees of fibrosis in the bilaminar zone.



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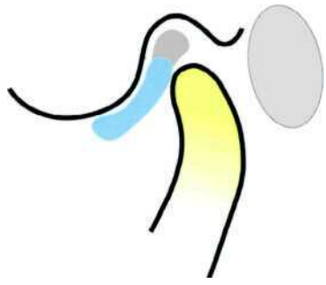
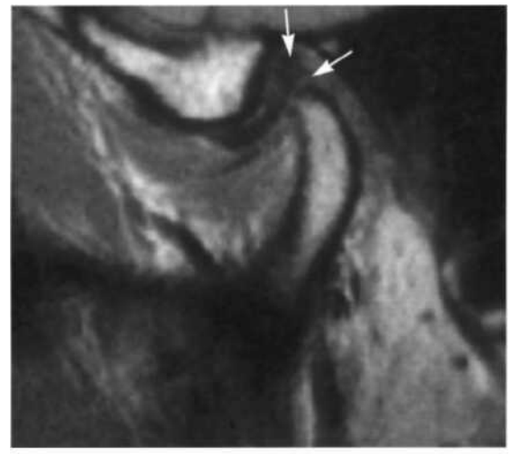
Progressive Adaptation in T1 - and T2-Weighted MRIs

Depending on the degree of disk displacement, 70-90% of all temporomandibular joints exhibit progressive adaptation (= fibrosis) of the bilaminar zone (Bumann et al. 1999). Patients with no signs of adaptation make up the majority in the group of so-called "temporomandibular joint patients" in dental practices.

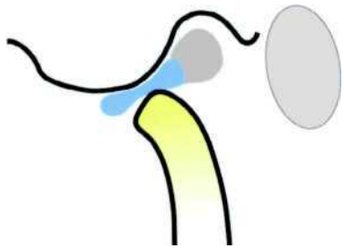
A progressive adaptation of the bilaminar zone can be diagnosed with certainty in MR images only through simultaneous representation of signal-poor structures in both T1- and T2-weighted scans. Signal-weak structures are often more striking in T1-weighted images because of the characteristic course of the collagen fibers (Christiansen and Thompson 1990). For this reason one must not rely on a single finding on this type of image. Fibrosis of a tissue depends primarily on the fibroblast activity that is induced by the activity of cytokinase-activated mast cells (Dayton et al. 1989). Interleukin 3 (IL 3) and neuropeptides are especially active in stimulating the proliferation of fibroblasts by way of the mast cells, and thereby increase the synthesis of collagen and proteoglycans (Casini et al. 1991). In the acute inflammatory phase of arthritis the number of mast cells decreases (Hukkanen et al. 1991).

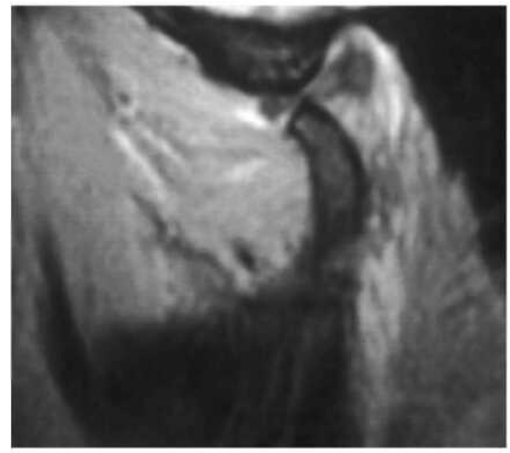




449 Progressive adaptation in a T1-weighted MRI
Left: Illustration of a joint with a tendency for anterior disk displacement and a broad, signal-poor structure (gray) dorsal to the pars posterior. (Jaws closed.)

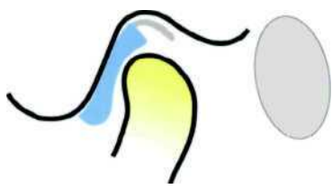
Right: T1-weighted MRI of a corresponding clinical situation. The broad signal-poor structure (arrows) dorsal to the pars posterior indicates a progressive adaptation of the bilaminar zone.

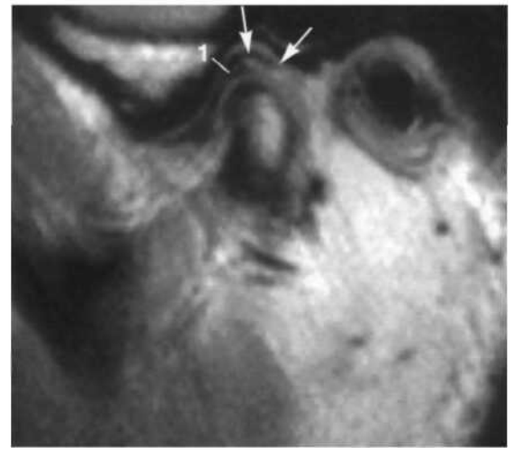




450 Progressive adaptation in a T2-weighted MRI
Left: Drawing of the same joint shown in Figure 449 at maximum jaw opening.

Right: T2-weighted MRI at maximum opening showing the repositioned disk.
Only with the additional information of a signal-poor structure in the T2-weighted scan can a diagnosis of progressive adaptation be made with certainty. In a T2-weighted MRI it is usually easierto distinguish the pars posterior from an adapted bilaminar zone.





451 Narrow progressive adaptation in T1-weighted MRI
Left: Drawing of a joint with a band of progressive adaptation of the superior stratum (gray) and the disk in its normal position.

Right: T1-weighted MRI showing normal disk position, a biconvex pars posterior (1), and a streaked, signal-poor structure (arrows) within the bilaminar zone. When narrow zones of progressive adaptation are associated with disk displacement, clicking sounds will usually be present clinically.

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Disk Adhesions in MRI

A disk adhesion is a restriction of translating movement by the articular disk relative to the temporal bone. It may occur with a disk that is displaced or with a disk in normal position. Patients are able to make normal jaw openings in spite of the disk adhesion. This is thanks to two compensating mechanisms:

- The hypomobility in the upper joint space is compensated for by hypermobility in the lower joint space.
- During jaw opening the relation between the rotating and translating components of movement shifts toward the rotational component.

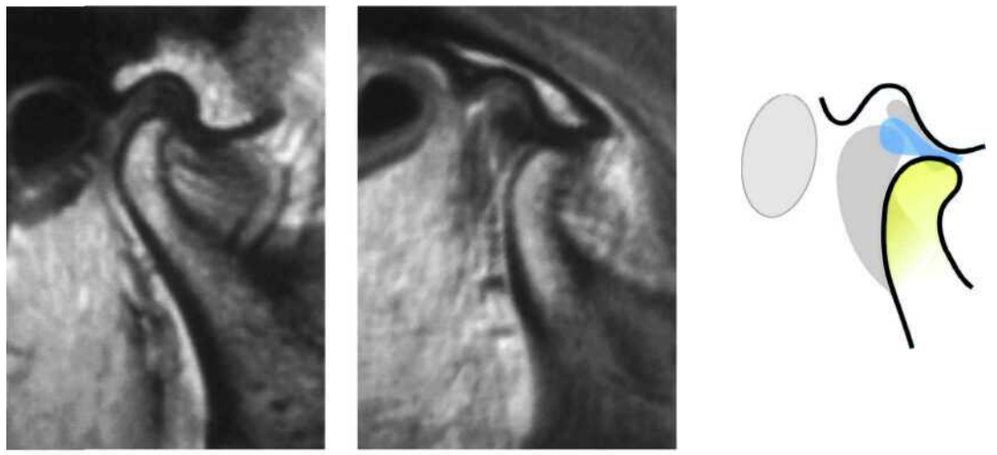
Clinically, a disk adhesion can be diagnosed only in combination with an anterior disk displacement. Disk adhesions without definite anterior disk displacement can be revealed only through MRI.

If a disk adhesion is associated with condylar hypermobility the condyle can, in exceptional cases, allow the disk to move anteriorly. This phenomenon has been reported and documented with imaging only once in the world literature (Wise et al. 1993).

452 Disk adhesion without disk displacement
Left: MRI in habitual occlusion shows a slight tendency for anterior disk displacement.

Center: At maximum jaw opening the condyle is almost on the crest of the articular eminence. The position of the disk, however, is unchanged.

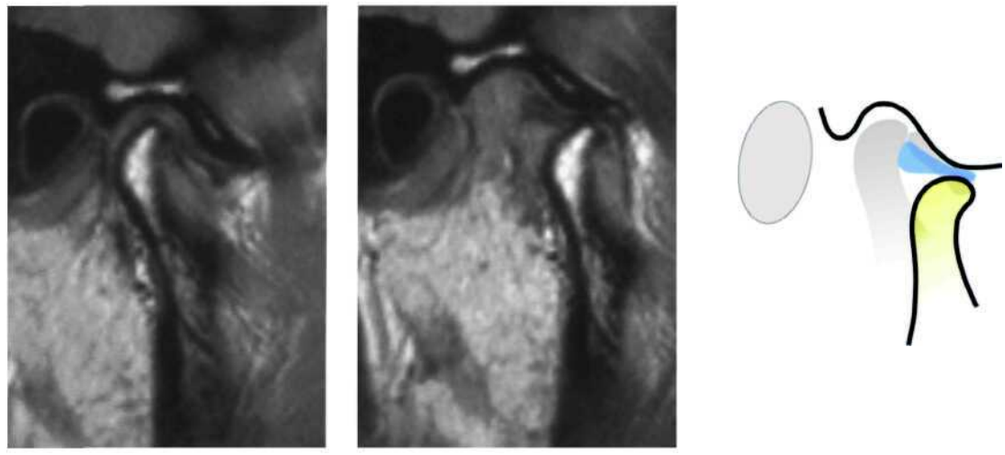
Right: Superimposition of the disk and condyle positions with the jaws closed (gray) and open (yellow and light blue).



453 Disk adhesion with disk displacement
Left: MRI with obvious anterior disk displacement in habitual occlusion.

Center. By superimposing a tracing of the fossa, articular eminence, and disk positions made with the jaws closed over this image made with the jaws open, it would become clear that the disk is indeed repositioned, although its translation is restricted.

Right: Schematic overlay of the disk and condyle positions with the jaws closed (gray) and open (yellow and light blue).



454 Disk adhesion with condylar hypermobility
Left: Intact disk-condyle relationship in habitual occlusion.

Center: At maximum jaw opening the disk has undergone minimal translation. The condyle, because of its hypermobility, is able to move anteriorly beyond the disk.

Right: Schematic superimposition of disk and condyle positions with the jaws closed (gray) and open (yellow and light blue).

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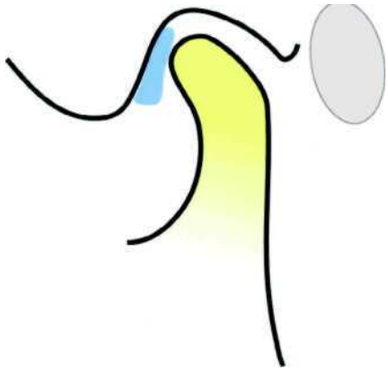
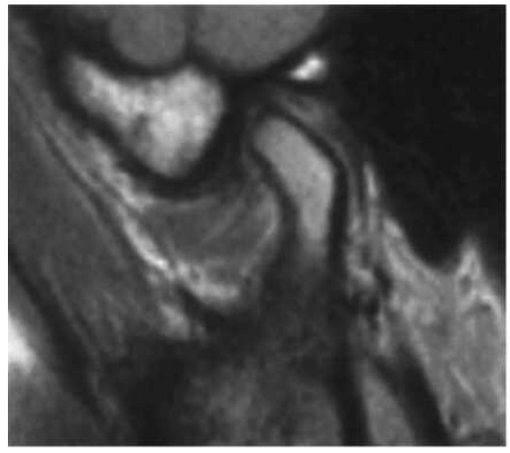
Disk Hypermobility

Disk hypermobility represents an initial stage of definite anterior disk displacement. It corresponds to stage I in the classification of the so-called "internal derangements" by Dawson (1989). It can be diagnosed clinically through dynamic compression and lateral dynamic translation with compression (pp. 108 and 111).

Whereas the clinical findings tend to be quite uniform, the appearance in MR images can vary considerably. We mention once again as a reminder that "absence of clinical clicking" is not to be equated with a normal disk position within the temporomandibular joint. It is quite possible for a tendency for anterior disk displacement to exist with no clinical signs of clicking.

For a diagnosis of disk hypermobility to be made, a *definite anterior disk displacement* must be detected in at *least one portion of the joint* (medial or lateral). In the other two slices there may be a tendency for disk displacement or a normal disk position. Here the MRI findings are identical to those of a partial disk displacement (p. 174). The two phenomena can be differentiated only through the dynamic test methods.

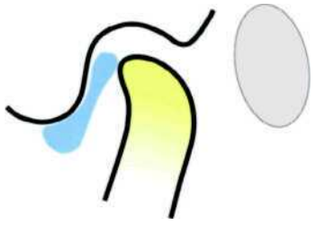


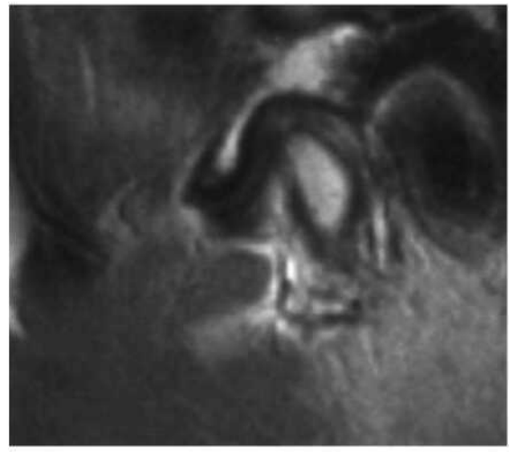


Disk hypermobility

455 Central slice
Left: Schematic of the disk-condlye relationship.

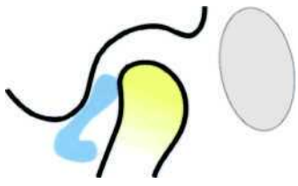
Right: Corresponding MRI of a 21-year-old female patient with disk hypermobility. Even though the pars posterior is flattened and the bilaminar zone has become progressively adapted, the tendency for anterior disk displacement is low.

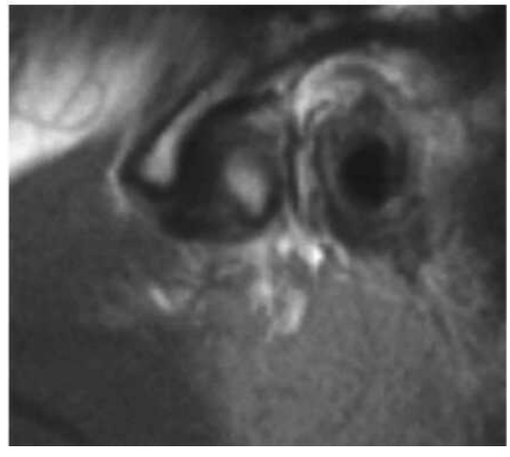




456 Centrolateral slice
Left: Schematic of the disk-condlye relationship.

Right: MRI of the same joint shown in Figure 455. In this slice the tendency for anterior disk displacement is more apparent. There is still contact between the pars posterior and the anterosuperior curvature of the condyle.





457 Lateral slice
Left: Schematic drawing of the disk-condyle relationship in the far lateral part of the joint.

Right: Corresponding MRI. In this part of the joint the pars posterior lies directly anterior to the condyle. In the clinic a clicking sound could be detected during dynamic compression (see also p. 108).

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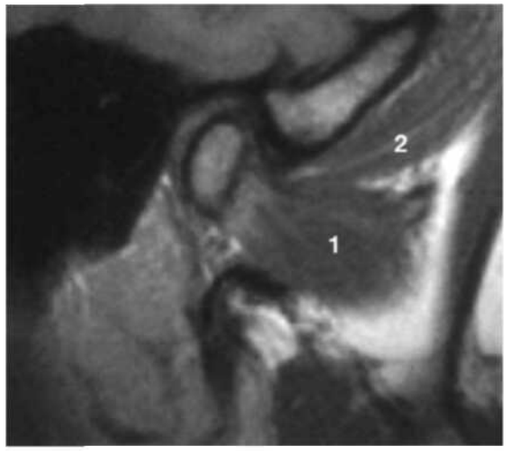
Partial Disk Displacement

The term "partial disk displacement" describes a three-dimensional positional relationship of the disk to the condyle and is a *summation of the two-dimensional disk positions* found in the medial, central, and lateral sections of the joint. The designation of partial or total disk displacement is completely independent of whether or not there is repositioning of the disk.

Because it is impossible to have an anterior disk displacement without stretching of the inferior stratum (Isberg and Isacsson 1986, Eriksson et al. 1992), it can be assumed that when there is a partial disk displacement, only a part of the inferior stratum is overstretched. This stretching and the displacement of the corresponding portion of the disk can affect either the lateral or the medial portion first. In 90% of partial disk displacements there is an anterior displacement of the lateral portion of the disk (deBont et al. 1986, Bumann et al. 1999); these are designated as partial *anteromedial* disk displacements. The other 10% are partial *anterolateral* disk displacements. The less the inferior stratum is stretched and the smaller the portion of the disk that is displaced, the more favorable are the structural conditions for a conservative repositioning treatment.

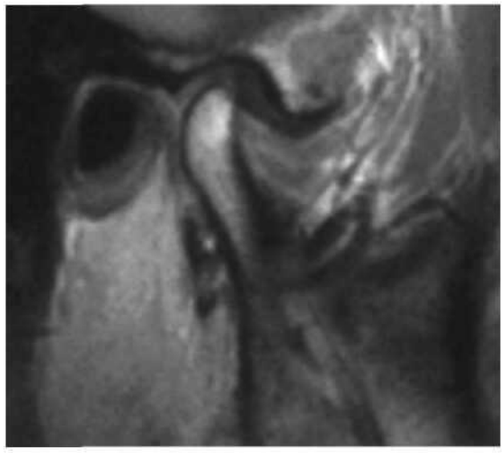
458 Medial portion of the joint
Left: MRI of the medial section of the joint of a 32-year-old female with nearly normal disk position. The pars posterior is somewhat flattened and the disk shows a minimal tendency for anterior displacement. In addition, one can easily identify both heads of the lateral pterygoid muscle (1, 2), which are never visible in lateral MRI slices.

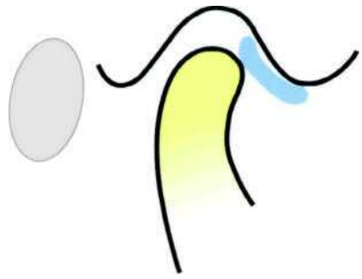
Right: Schematic drawing of the corresponding disk-condyle relationship.



459 Central portion of the joint
Left: MRI of the central portion of the same joint. Here a definite anterior disk displacement is already present because the pars posterior lies in front of the most anterosuperior point on the condyle. If in this slice there were a normal disk position or only a tendency for anterior displacement, the structural conditions for a repositioning treatment would be more favorable.

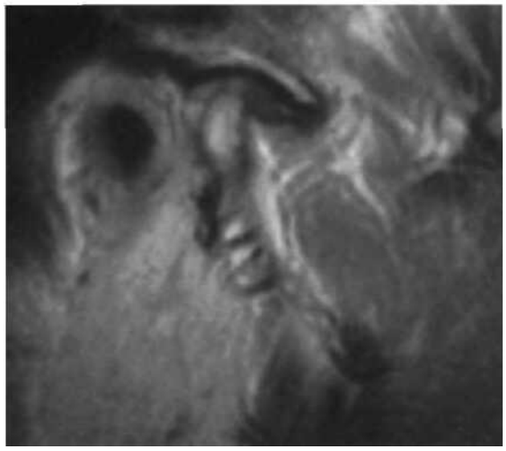
Right: Schematic drawing of the corresponding disk-condyle relationship.

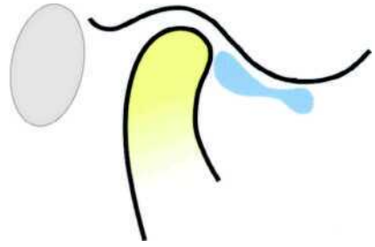




460 Lateral portion of the joint
Left: In this slice anterior displacement of the disk can clearly be seen. The pars posterior is still convex and the condyle, likewise, still has its normal shape. Overall this joint has a partial anteromedial disk displacement since the lateral portion of the disk is rotated in the anteromedial direction.

Right: Schematic drawing of the corresponding disk-condyle relationship.





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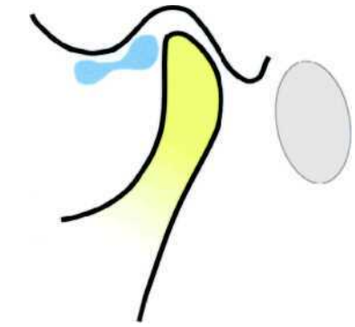
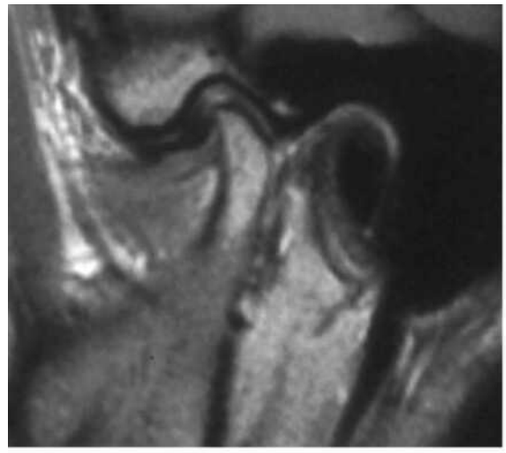
Total Disk Displacement

The incidence of anterior disk displacements in a random patient sample of young adults was approximately 12% (Solberg et al. 1979). Among patients with functional disturbances an incidence of up to 85% has been reported (Sanchez-Woodworth et al. 1988b, Paesani et al. 1992). The parameters for a treatment decision were discussed earlier (pp. 120f). A total disk displacement is present when there is a *definite anterior displacement in all three slices* with the pars posterior in front of the anterosuperior contour of the condyle. Whereas a partial disk displacement (= overstretching of the posterolateral portion of the inferior stratum) requires a continuous posterolateral or posterosuperolateral loading vector, a total disk displacement (= overstretching of the entire inferior stratum) requires a posterior or posterosuperior loading vector. The direction of the loading vector can be deduced from the shape of the pars posterior: If a totally displaced disk still has a convex pars posterior, there is probably a purely *dorsal loading vector*. If, however, the pars posterior has a flattened wedge-shape, a posterosuperior loading vector can be assumed.

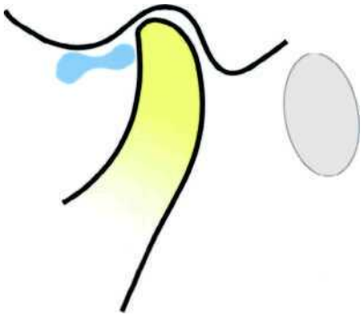
Total disk displacement

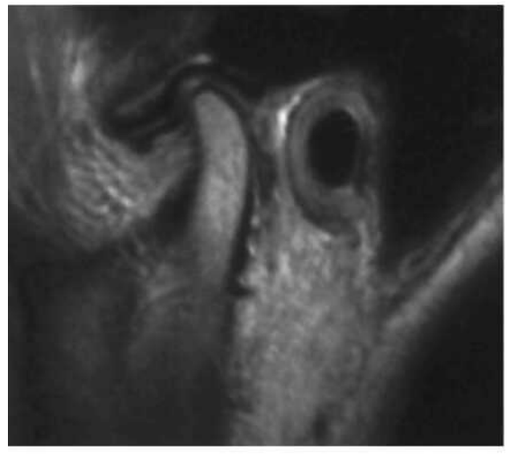




461 Medial portion of the joint
Left: Schematic drawing of the disk-condyle relationship.

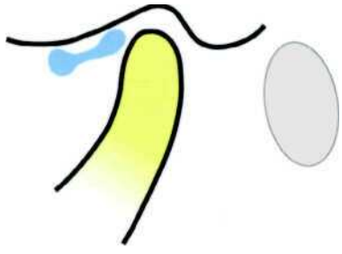
Right: MRI of a joint with a more definite anterior disk displacement. The pars posterior of the disk still has a biconvex form. This finding is evidence of a posterior loading vector, which is also reflected by the relatively posterior positioning of the condyle and can be verified clinically by the lack of adaptation found during the passive compression test.

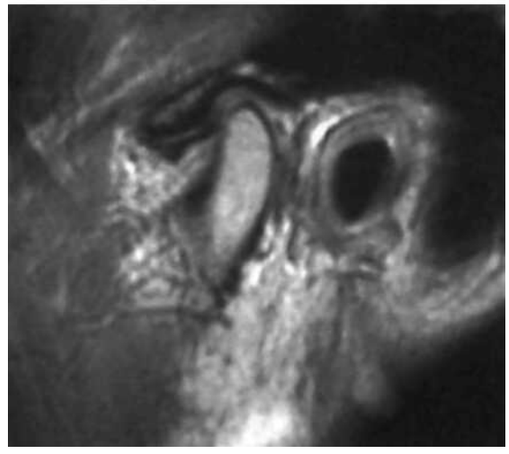




462 Central portion of the joint
Left: Schematic drawing of the disk-condyle relationship.

Right: The MRI shows a definite anterior disk displacement. The pars posterior of the disk appears somewhat more flattened than in the medial slice.
The MRI findings never dictate the necessity of repositioning a displaced disk. They only provide supplemental information to be added to the structural parameters making treatment decisions (see also p. 121).





463 Lateral portion of the joint
Left: Schematic drawing of the disk-condyle relationship.

Right: In a lateral slice too the MRI shows a definite anterior disk displacement. In this joint the disk displacement is total. Because overstretching of the entire inferior stratum is an absolute prerequisite for this type of disk displacement, the structural conditions here are less favorable than with only a partial disk displacement.

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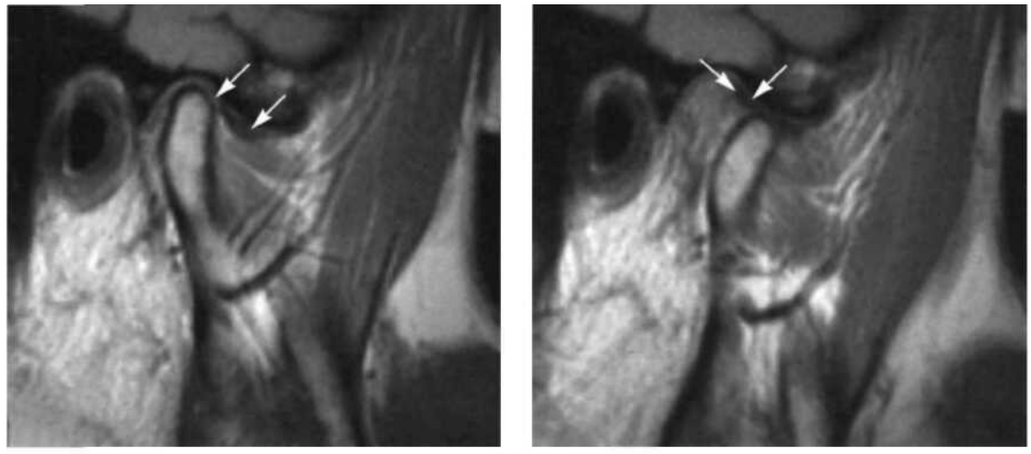
Types of Disk Repositioning

A disk that is displaced anteriorly when the teeth are in habitual occlusion can experience varying degrees of repositioning during an excursive movement (Bumann et al. 1999). A distinction can be made, therefore, among *total repositioning, partial repositioning,* and *displacement without repositioning.* This three-dimensional finding is always based on an evaluation of at least two portions of the joint (lateral and medial). The degree of repositioning is significantly correlated with the extent of disk displacement in habitual occlusion. Both the presence of elastic fibers in the disk (Christensen 1975, Mills et al. 1994) and the release and reabsorption of free water through the glycosaminoglycans (Dannhauer 1992) serve to reshape the disk when the tissue relaxes following repositioning. The less completely a disk becomes repositioned on the condyle during excursive movements, the poorer the prospects for long-term stabilization of the disk through conservative treatment with a repositioning splint (Okeson 1988, Moloney and Howard 1986). In many cases the exact degree of repositioning can be determined clinically through specific examination techniques, but in some cases it can be determined only through MRI.

464 Disk displacement with total repositioning
Left: In habitual occlusion, the disk is displaced anteriorly and the pars posterior is flattened (arrows).

Right At maximum jaw opening the condyle has made an evident anterior translation. Because during jaw opening the disk has moved posteriorly relative to the condyle, complete repositioning of the disk is seen in this slice. The pars posterior has resumed its biconvex shape (arrows).

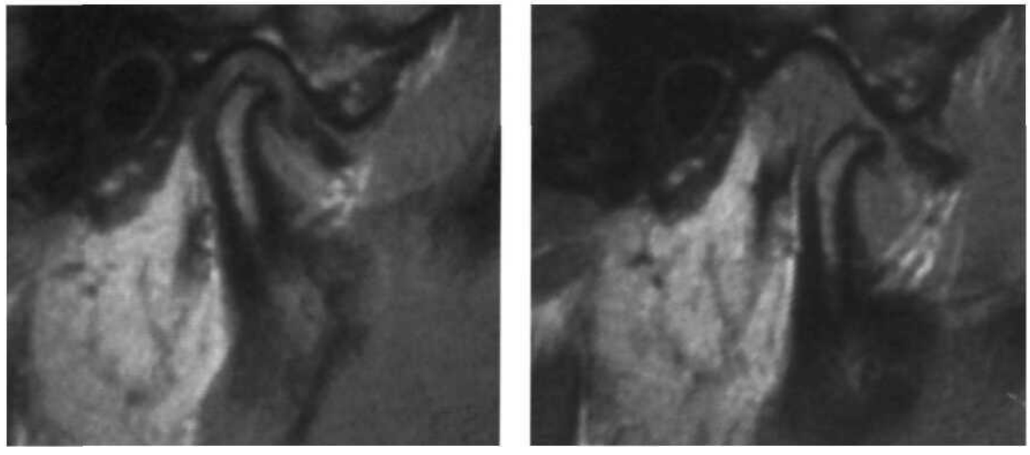


465 Disk displacement with partial repositioning
Left: With the teeth in habitual occlusion, the disk is displaced anteriorly. The pars posterior (arrows) of the disk is not deformed.

Right: At maximum jaw opening both the condyle and disk have made a distinct anterior translation.
The position of the vertex of the condyle (arrow) against the pars posterior instead of against the pars intermedia (outlined arrow) is a sign of incomplete repositioning.

466 Disk displacement without repositioning
Left In habitual occlusion, the disk is displaced anteriorly and is slightly deformed. There are also degenerative changes on the condyle.

Right: During jaw opening, the condyle and disk have made a wide anterior translation. Nevertheless, no repositioning is seen in this slice. Judging whether or not there is repositioning of a disk in all three dimensions should never be based on one single slice.



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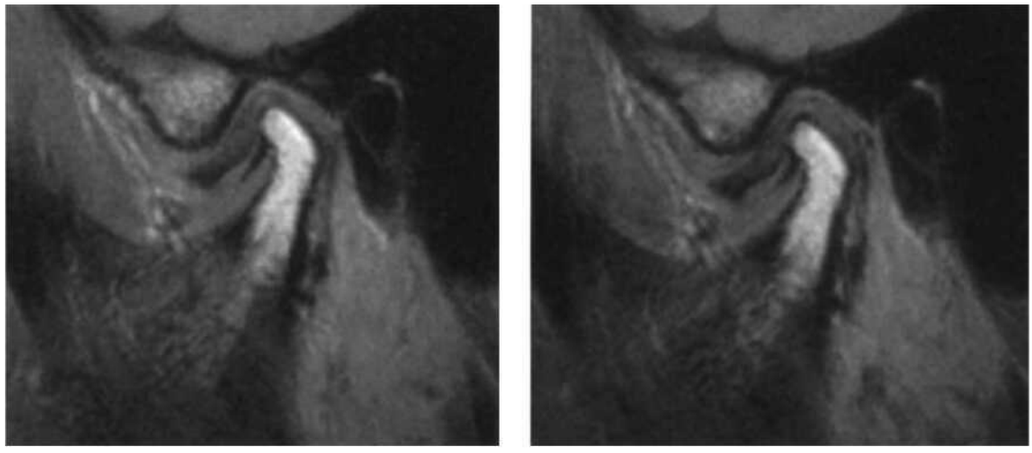
Disk Displacement without Repositioning

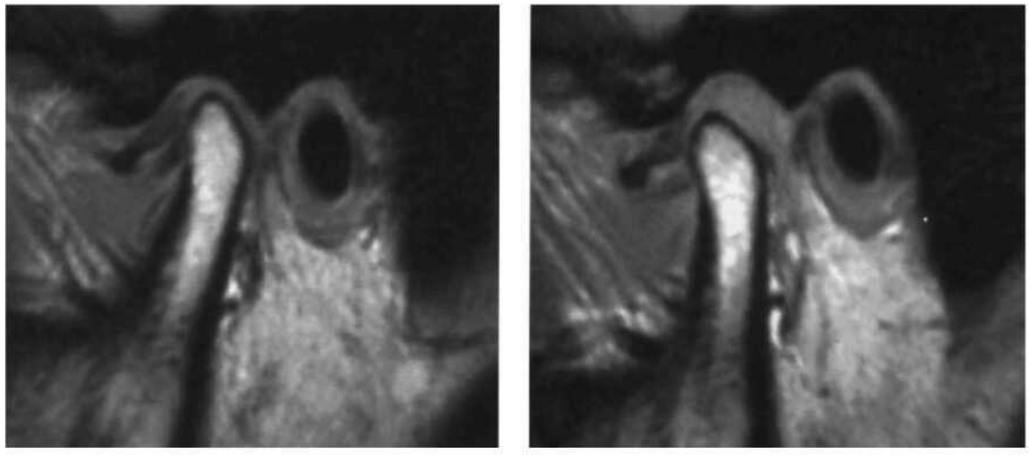
Sometimes MRI is necessary to verify a presumed clinical diagnosis of disk displacement without repositioning. While it is true that conventional clinical examination techniques are highly specific, they are not very sensitive (Yatani et al. 1998b). As a rule, joint radiographs of patients with disk displacement without repositioning cannot be distinguished from those of healthy patients (Sato et al. 1998). Two out of three patients with disk displacement without repositioning verified by MRI experience no complaints whatsoever. Even after using passive manual examination techniques, one third of the patients show no abnormal clinical signs (Johannson and Isberg 1991, Bumann et al. 1999). These patients require no treatment because they are completely adapted.

In addition to verification of the presumptive clinical diagnosis, MRI can provide information on the extent of displacement in the sagittal plane with the teeth in habitual occlusion, the degree of deformation of the disk, the shape of the pars posterior, the shape of the condyle, the extent of condylar translation in the affected joint, and the presence of fibrosis (adaptation) in the bilaminar zone.



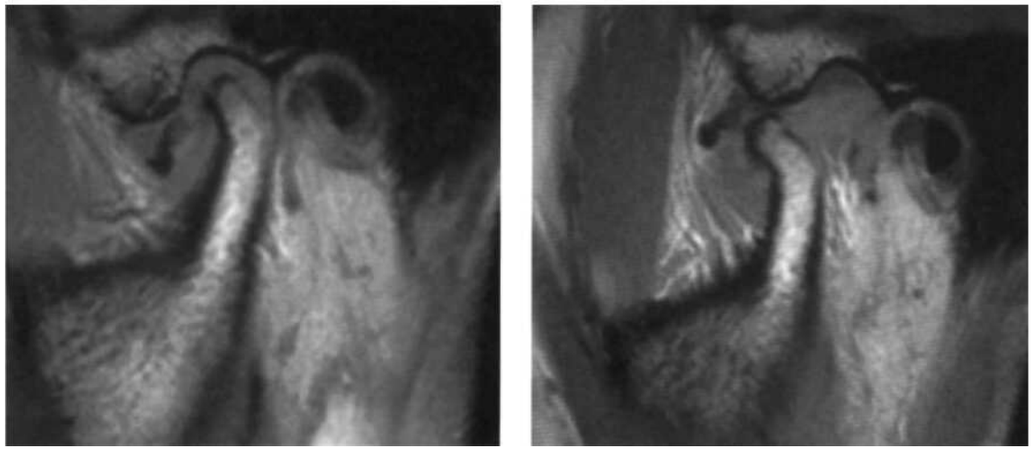
467 No translation
Left: With the teeth in habitual occlusion, the disk in this slice lies entirely in front of the condyle. It is slightly deformed, and in the bilaminar zone signal-poor structures indicating fibrosis (adaptation) can be plainly seen.

Right: At maximum jaw opening only minimal translation of the condyle has occurred. The relation of the disk to the condyle has not improved during opening.



468 Restricted translation
Left: With the teeth in habitual occlusion the picture is similar to that seen in Figure 467, except that here the condyle is somewhat more flattened. In 60% of patients exhibiting disk displacement without repositioning, the clinical symptoms regress spontaneously within 1 year (Lundh et al. 1992, Kurita et al. 1993). The degree of opening bears no relation to the treatment prognosis.

Right: At maximum jaw opening the limited translation of the condyle is evident.



469 Normal translation
Left: With the teeth in habitual occlusion the disk is displaced far anteriorly and deformed (overstretched bilaminar zone). The condyle is also deformed.

Right: Maximal jaw opening is not restricted in spite of the fact that the disk is still displaced. The younger the patient, the more favorable the prognosis for progressive adaptation (Sato et al 1997). Nevertheless, 40% of these patients should receive appropriate treatment.

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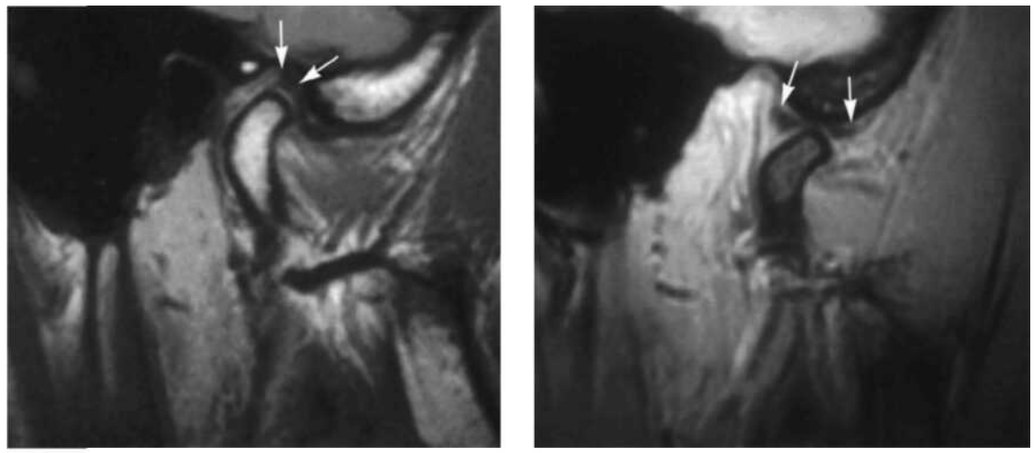
Partial Disk Displacement with Total Repositioning

A comprehensive description of the disk-condyle complex must include a summary of the MRI findings in three sections (medial, central, and lateral) in habitual occlusion and at maximum jaw opening. The most favorable type of displacement diagnosed in this way is partial disk displacement with total repositioning. Further differentiation can be made between stable and unstable repositioning. This distinction can be made clinically through incursive dynamic compression (sensitivity 0.87, specificity 1.00) or in MRI by determining the shape of the pars posterior (biconvex or flattened).

According to our investigations, in 90% of 181 patients with partial disk displacement, the lateral portion of the disk was displaced anteriorly. Left joints (94%) are affected almost as often as right joints (87%). No sex-linked differences were found. In a selected group of patients of a physical therapy consultation, 90% of patients with partial disk displacement exhibited total repositioning. (Bumann et al. 1999). In addition to a partial overstretching of the inferior stratum, total repositioning is a favorable structural condition for repositioning therapy.

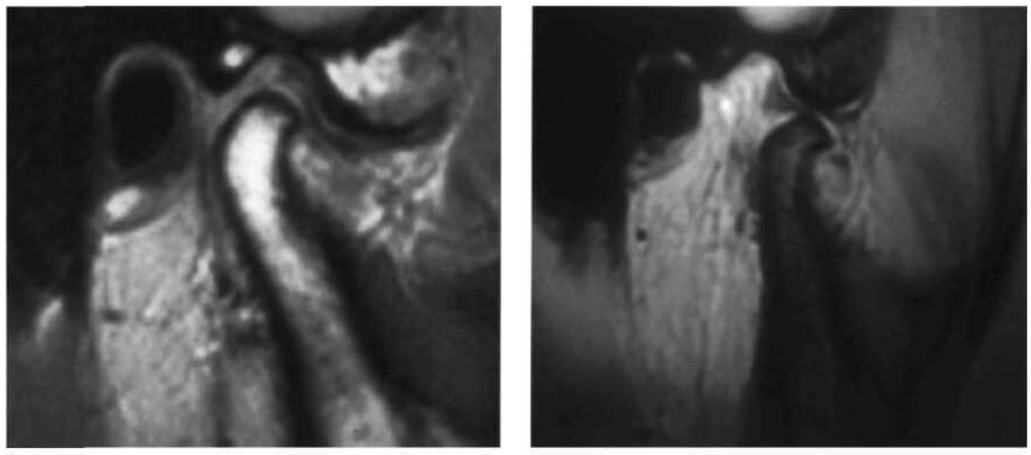
470 Medial portion of the joint
Left: MRI in habitual occlusion. There is a slight tendency for anterior disk displacement. At first glance, the well-adapted portion of the bilaminar zone (arrows) gives a false impression of a normally positioned disk. From a functional viewpoint, the formation of a pseudodisk has maintained an intact disk-condyle complex.

Right: At maximum jaw opening the true disk (arrows) lies in its physiological position between the condyle and articular eminence.



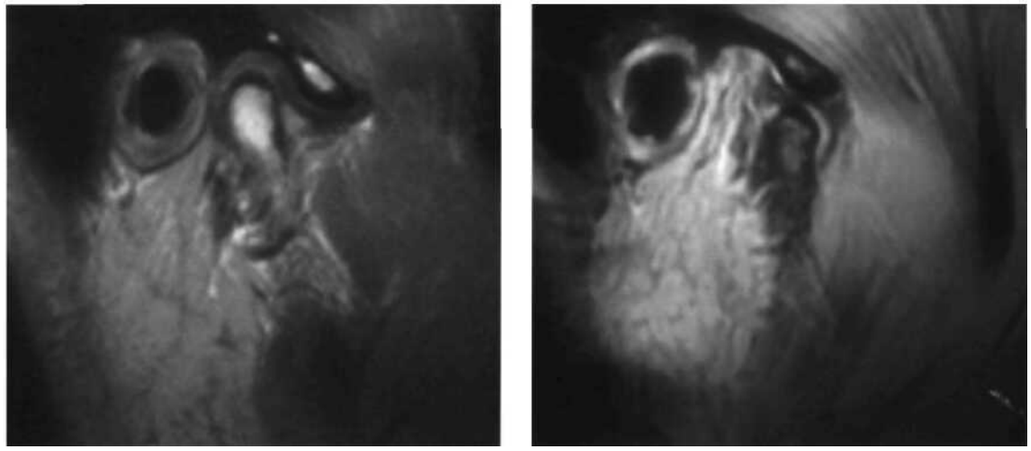
471 Central portion of the joint
Left: The boundary between the pars posterior and the progressively adapted bilaminar zone can be identified more clearly in this MRI of the central portion of the joint in habitual occlusion. The morphological description is a "definite anterior disk displacement with progressive adaptation of the bilaminar zone."

Right: At maximum jaw opening the disk is again in its normal position between condyle and articular eminence.



472 Lateral portion of the joint
Left: The MRI shows a definite anterior disk displacement with no significant progressive adaptation of the bilaminar zone. The MRI findings can be summarized as a partial disk displacement in habitual occlusion. The pars posterior is flattened.

Right: Lateral slice at maximum jaw opening. Because here, too, the disk is seen in a physiological position between the condyle and articular eminence, the diagnosis is a partial disk displacement with complete stable repositioning.



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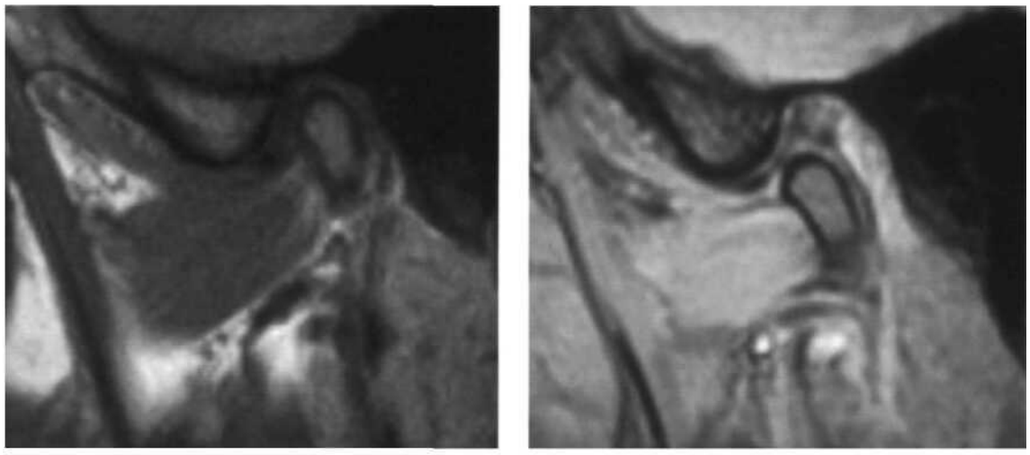
Partial Disk Displacement with Partial Repositioning

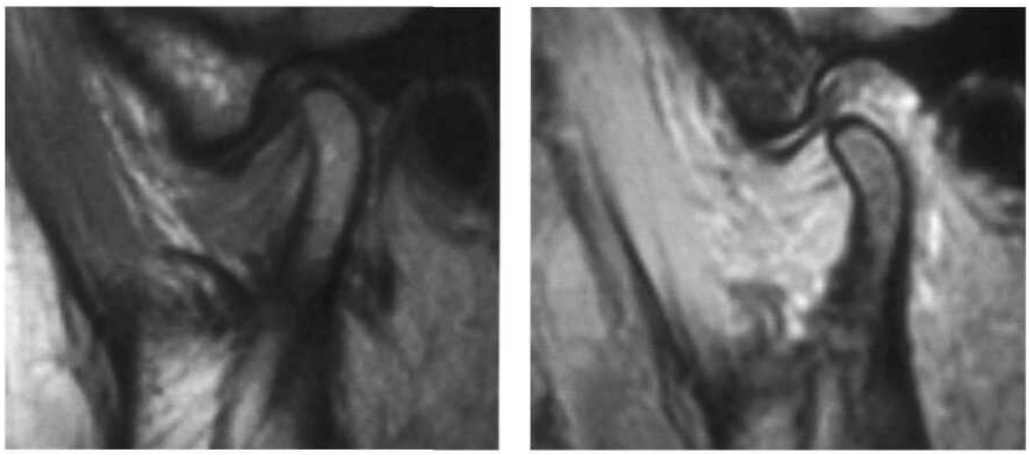
When there is partial disk displacement with partial repositioning, two of the three MRI slices in habitual occlusion will usually show a definite disk displacement. The third slice, almost always the medial, will show either a normal disk position or a tendency for anterior displacement. The occurrence of a partial disk displacement can be traced back to a pronounced posterior condyle position in the lateral portion of the joint. At maximum jaw opening a definite anterior disk displacement can be seen in at least one slice.

Approximately 8% of all partial disk displacements reposition only partially during jaw opening, and in only approximately 1% of partial disk displacement is there no repositioning (Bumann et al. 1999). Partial repositioning can be diagnosed clinically through passive compression only if there is no adaptation in the bilaminar zone of the affected joint. The history of a patient with partial disk displacement with partial repositioning can vary from no clinical symptoms or only painless clicking sounds to the classic symptoms of a disk displacement without repositioning.



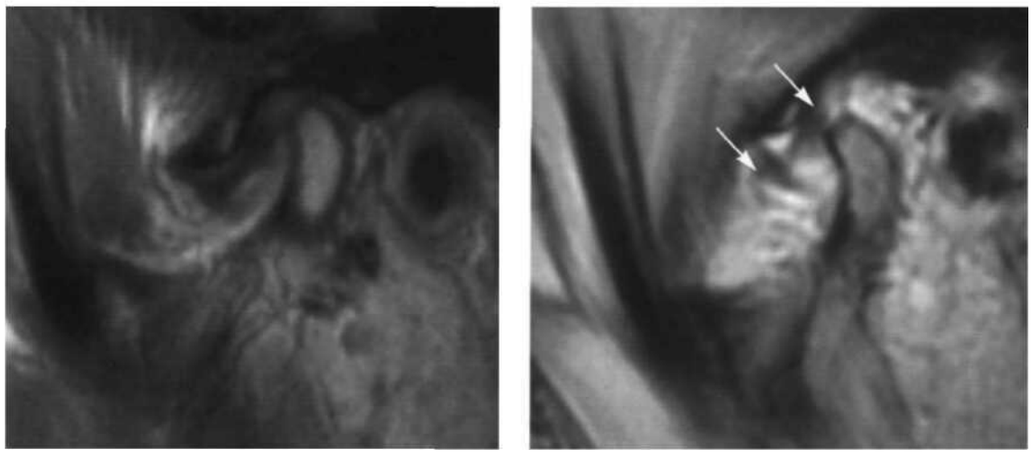
473 Medial portion of the joint
Left: MRI in habitual occlusion. There is a slight tendency for anterior displacement of the disk in relation to the condyle.

Right: Corresponding MRI slice in the open position. Translation of the condyle is seen to be restricted, which correlates with the clinical finding of limited mouth opening. The pars posterior cannot be delineated with the same certainty as in the previous case. The bilaminar zone shows signs of progressive adaptation.



474 Central portion of the joint
Left: This MRI shows the contours of the disk more clearly than does the lateral slice. The disk is definitely displaced anteriorly. The pars posterior is slightly flattened.

Right: At maximum jaw opening the limitation of translation is again apparent: the pars posterior lies directly over the anterosuperior contour of the condyle. Repositioning during jaw opening is incomplete.



475 Lateral portion of the joint
Left: In the lateral slice the disk is again clearly seen to lie well ahead of the condyle, and its pars posterior is slightly flattened. The position of the condyle is more posterior relative to the fossa than it is in the other slices.

Right: Maximum jaw opening. The lateral slice likewise shows no repositioning of the disk, which again is seen definitely anterior to the condyle. The clicking sound detected clinically can be attributed to the partial repositioning in the central portion of the joint.

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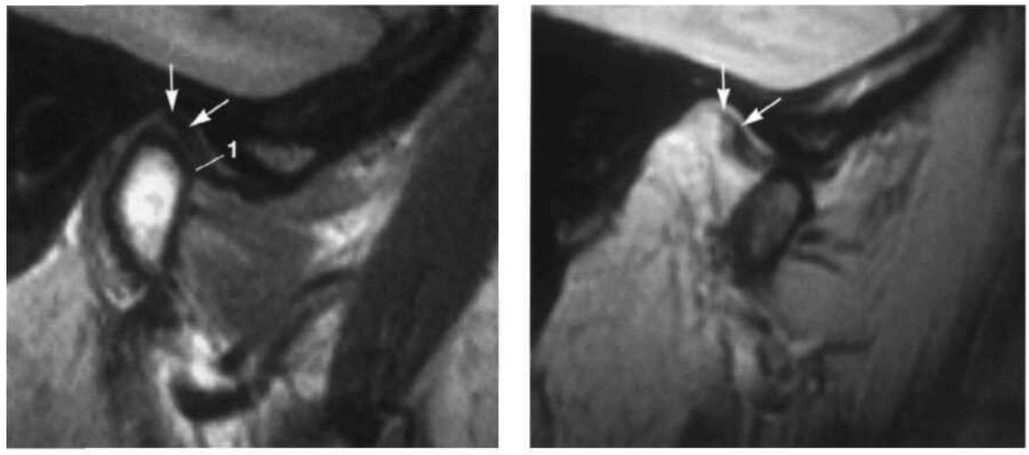
Total Disk Displacement with Total Repositioning

When there is total disk displacement with total repositioning, the MR images with the jaws closed show the disk lying definitely anterior to the condyle in *all three slices,* and with the jaws open there is complete repositioning. Of 418 patients with total disk displacement examined as part of a temporomandibular consultation, only 39% exhibited total repositioning. In the male patients, total repositioning could be demonstrated in 33%, and there was no repositioning in 53%. Among the female patients the percentages were almost reversed (Bumann et al. 1999). Because of overstretching of the entire inferior stratum that always accompanies total disk displacement and the low incidence of complete repositioning, total disk displacement with total repositioning represents a *less favorable morphological condition for conservative repositioning therapy* than partial disk displacement with total repositioning. When there is total disk displacement 27-35% of the condyles are in a more posterior position within the fossa. Disk displacements are not necessarily associated with a posterior condylar position and can also occur in centric condylar position.

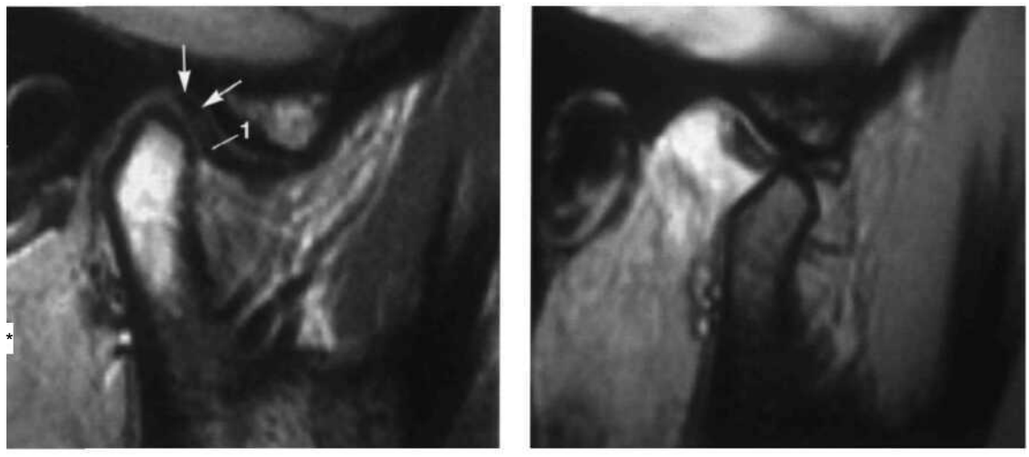
476 Medial portion of the joint
Left: T1-weighted MRI in habitual occlusion. The disk is definitely anterior to the condyle. Dorsal to the pars posterior (1) there is extensive progressive adaptation of the bilaminar zone (arrows). With this type of pronounced fibrosis it is often the case that no clicking sounds can be detected clinically.

Right: At maximum jaw opening the disk is completely repositioned. The repeated weak-signal image of the bilaminar zone (arrows) confirms the diagnosis of "progressive adaptation."



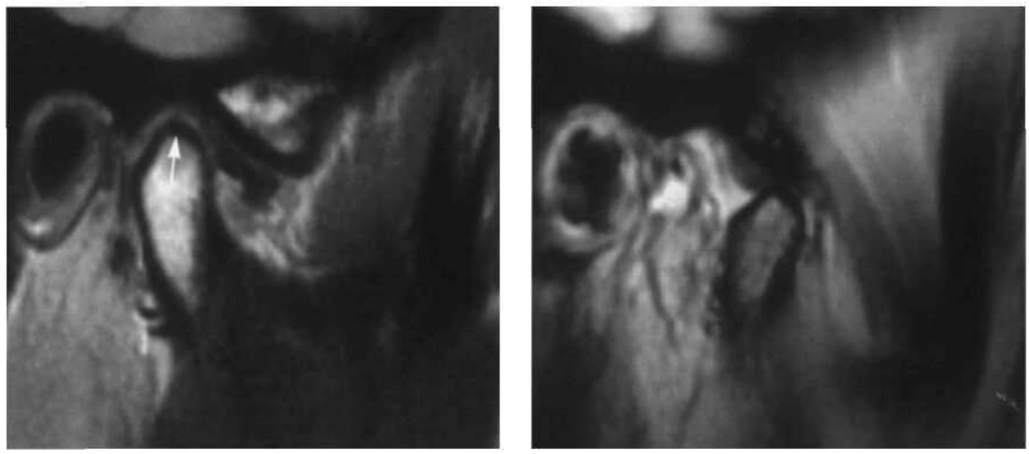
477 Central portion of the joint
Left: In this T1 -weighted MRI in habitual occlusion the relationships are similar. The pars posterior (1) definitely lies in front of the condyle, and the bilaminar zone lying between the condyle and articular eminence is perfectly adapted (arrows). The only clinical symptom is a slight tenderness to posterosuperior passive compression.

Right: Here too, complete repositioning is seen when the jaws are opened maximally.



478 Lateral portion of the joint
Left: This T1-weighted scan also shows definite anterior disk displacement and slight deformation of the disk. The fibrosis of the bilaminar zone is not as noticeable here as in the other two slices. The cortical bone is thickened superiorly (arrow).

Right: Nevertheless, there is complete repositioning when the jaws are opened. When all six slices are considered together, the diagnosis is "total disk displacement with total repositioning".



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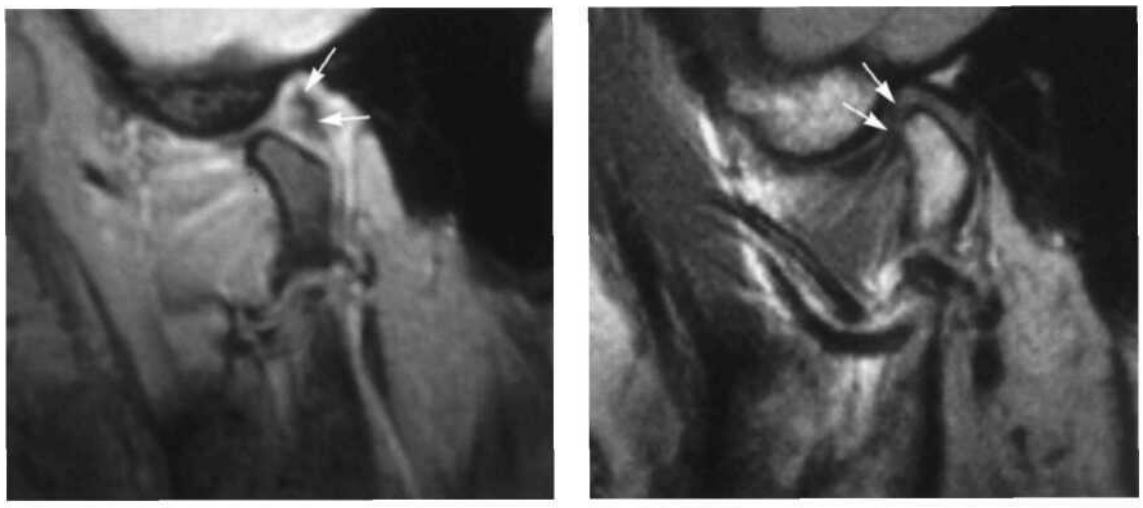
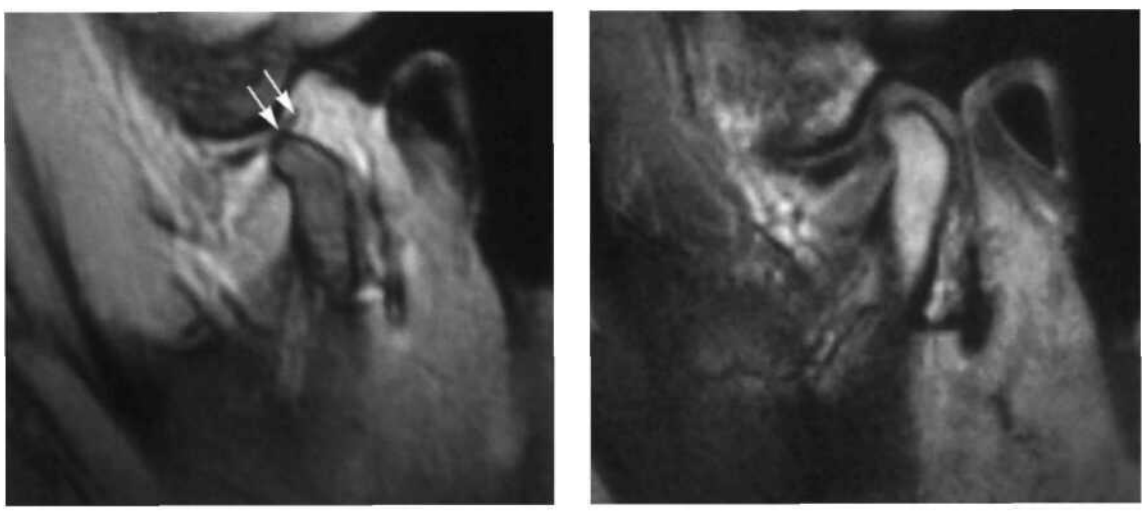
Total Disk Displacement with Partial Repositioning

Still another form of disk displacement is total disk displacement with partial repositioning. This made up approximately 5% of all disk displacements in a selected group of patients. With the teeth in habitual occlusion the disk completely displaced anterior to the condyle. Fibrosis in the bilaminar zone above the vertex of the condyle shows up on MRI as a dark, signal-poor structure. If this is the case in all three sections, no pain will be elicited clinically by dynamic compression or by passive superior, mediosuperior, and laterosuperior compressions. During jaw opening, the disk is incompletely repositioned on the condyle (= partial repositioning). Repositioning can fail to occur on either the lateral or medial side of the joint. In over 90% of patients, repositioning does occur in the medial portion of the joint while the condyle is seen resting on the pars posterior in the central MRI slice; in the lateral portion of the joint the disk lies entirely in front of the condyle. Total disk displacement can be diagnosed clinically through dynamic tests, but partial repositioning, on the other hand, can often be diagnosed only through MR imaging.



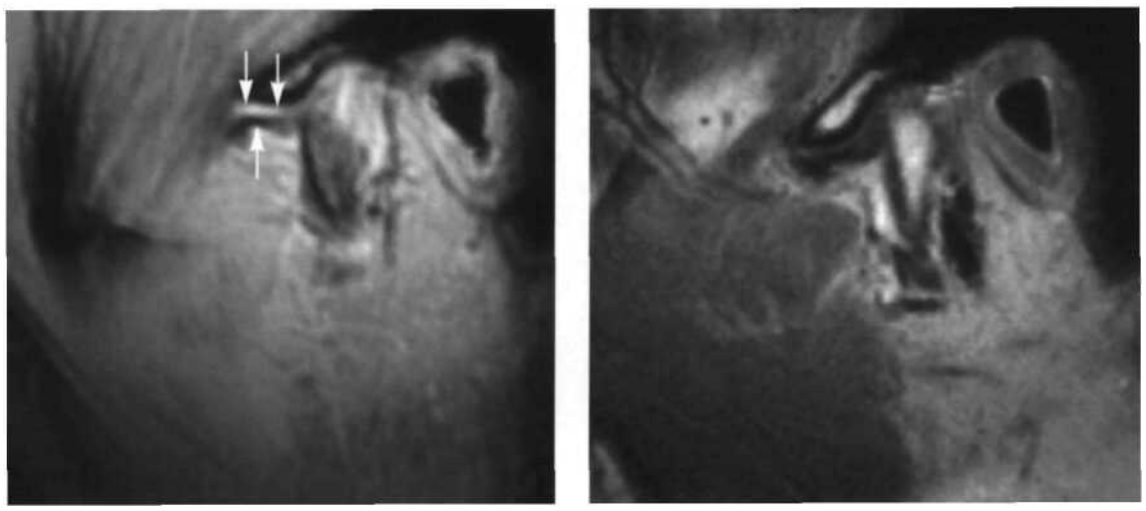
479 Medial portion of the joint
Left: At maximum jaw opening the pars intermedia of the disk is completely repositioned. Distal to the signal-intensive pars posterior *(light)* the signal-poor fibrosis (arrows) can be clearly seen in the region of the bilaminarzone.

Right: The condyle is virtually in the center of the fossa. The disk is definitely displaced anteriorly, and the pars posterior is flattened on both sides. Distal to the pars posterior adaptations can be seen in the form of a pseudodisk (arrows).



480 Central portion of the joint
Left: At maximum jaw opening only portions of the pseudodisk (arrows) can be seen atop the condyle. The pars posterior and pars intermedia still lie anterior to the condyle even though the jaws are open.

Right: Here too, the condyle is resting at the center of the fossa. There is a total anterior displacement of the disk, and the pars posterior is flattened on both sides. The distinctly formed pseudodisk can, as in the medial slice, give the false impression of a partial disk displacement.



481 Lateral portion of the joint
Left: At maximum jaw opening there is no repositioning of the disk. Because translation is only slightly limited, the disk has become folded. There is effusion present (arrows) in both joint spaces.

Right: Here the pars posterior is lying in front of the condyle and is still very convex. Distal to the pars posterior a broad pseudodisk can be seen that is just as thick as the pars posterior. In this portion of the joint the shape of the disk is still nearly biconcave.

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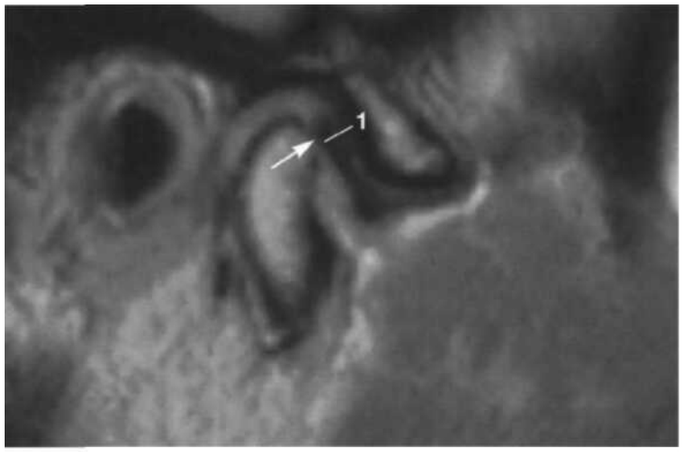
Condylar Hypermobility

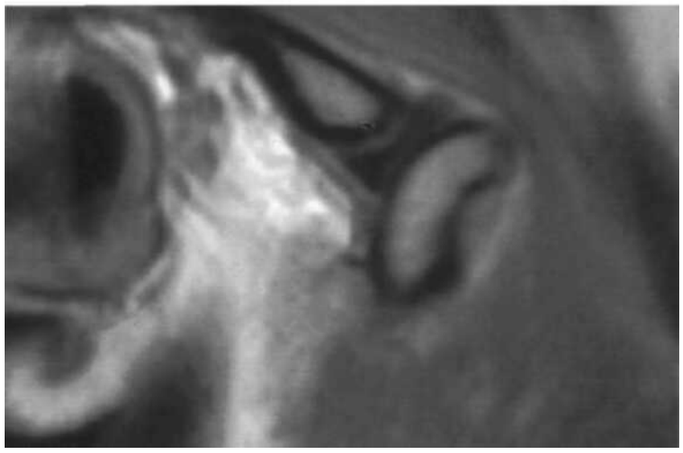
Condylar hypermobility is the over-rotation of the disk-condyle complex past the crest of the articular eminence during jaw opening (Schultz 1947). This phenomenon can also be found in healthy test subjects who have no temporomandibular problems (Wooten 1966). If the patient cannot close the jaws from this position without assistance, the condition is referred to as *luxation of the condyles.* The clinical diagnosis of condylar hypermobility is not an indication for MRI. In cases of disk displacement with or without repositioning, condylar hypermobility occurs quite frequently.

The disk position merits special attention when there is condylar hypermobility and the jaws are opened to their maximum. Because of the hypermobile joint capsule and overstretched lateral ligament, the condyle may make an unusually wide anterior translation. Then the disk will find itself more posterior to the condyle than usual. This, however, is a physiological position and should not be confused with a posterior disk displacement or a disk displacement during excursive mandibular movement.

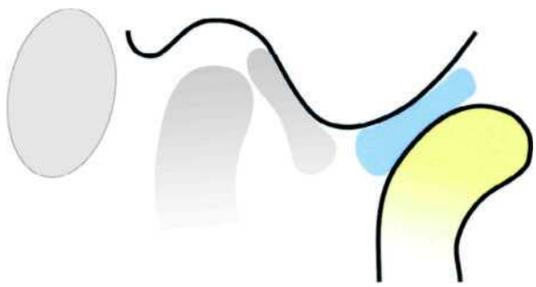
482 MRI in habitual occlusion
With the jaws closed the condyle is relatively concentric with the glenoid fossa. The disk shows a tendency for anterior displacement. The pars posterior (1) of the disk, however, is clearly seen to still have contact with the anterosuperior contour of the condyle (arrow). Therefore, during jaw opening there is no clinical sign of a disk-related clicking sound.



483 MRI at maximum jaw opening
Seen here is a hypermobile condyle with an extreme anterior component of translation. Both disk and condyle lie well anterior to the crest of the articular eminence. Because of the exaggerated anterior movement of the condyle, the disk has completed an equally exaggerated posterior movement relative to the condyle. *This is not a posterior disk displacement* because there is still functional contact between the disk and condyle.



484 Schematic superimposition of the two positions
The drawing clarifies once more the changes in the positions of the disk and condyle that occur with condylar hypermobility. The disk position with the jaws closed (gray structures) is not displaced posteriorly, as it would be with a diagnosis of posterior disk displacement. At maximum jaw opening (colored structures) functional contact of the joint surfaces is still present. This differentiates condylar hypermobility from disk displacement during excursive mandibular movements.



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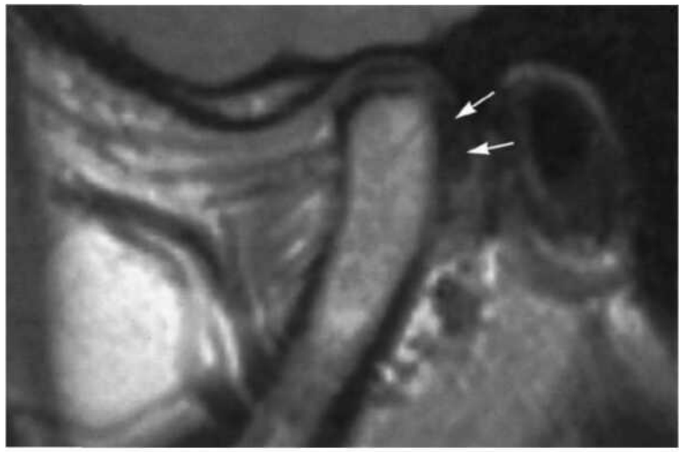
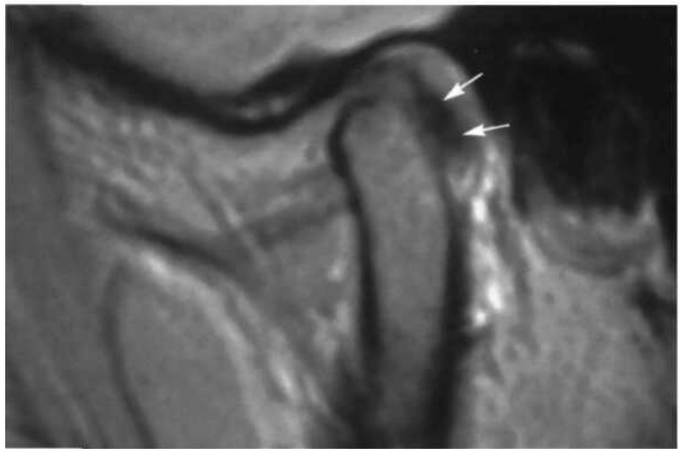
Posterior Disk Displacement

As a rule, posterior disk displacements are only found following trauma and are relatively rare (Blankenstijn and Boering 1985, Gallagher 1986). Here the condyle is anterior to the pars anterior of the disk regardless of whether the jaws are open or closed. During jaw closure the disk is compressed in the retrocondylar space. In this way posterior disk displacement can be distinguished from disk displacement during excursive movements in which the disk is positioned normally during habitual occlusion (Klett 1985, 1986a, b). With posterior disk displacement translation of the condyle is not ordinarily restricted, and for this reason these patients seldom experience limitation of mouth opening. In a diseased joint, of course, there is often pain, especially while the jaws are being closed. The protective reflex of holding the condyle forward results in a lateral open bite and deviation of the midline toward the healthy side. Whereas a few years ago, a definitive diagnosis had to be made with arthrographs (Westesson 1982), today MRI is the diagnostic aid of choice (Westesson et al. 1998).



485 Posterior disk displacement in habitual occlusion
A central MRI slice of the left temporomandibular joint (of a 48-year-old female patient). The bony contour of the condyle appears somewhat flattened and irregular. Upon superficial inspection the disk cannot be clearly delineated. However, a signal-poor structure (arrows) is noticeable posterior to the condyle. In this T1-weighted image, the signal-poor structure above the condyle could be interpreted as either a flattened disk or as an area of progressive adaptation.



486 Posterior disk displacement with the jaws open
This image makes the posterior disk displacement apparent. The patient's jaw opening was severely limited by extensive fibrosis, which was confirmed later during surgery. The posteriorly displaced disk (arrows) is now easier to recognize than in Figure 485, even though in both jaw positions the relative location of the disk is the same. The progressive adaptation in the superior portion is also confirmed.

487 Graphic overlay
Superimposition of drawings of the disk-condyle complex in the closed and maximally opened positions illustrates more clearly the chronic posterior position of the disk. With the jaws closed there is no functionally articulating contact between the disk and condyle. This distinguishes a posterior disk displacement from condylar hypermobility and disk displacement during excursive mandibular movements.

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Disk Displacement during Excursive Movements

When a disk is positioned posteriorly, a differential diagnosis must be made from among condylar hypermobility, posterior disk displacement, and disk displacement during excursive movements by considering the following distinguishingcharacteristics:

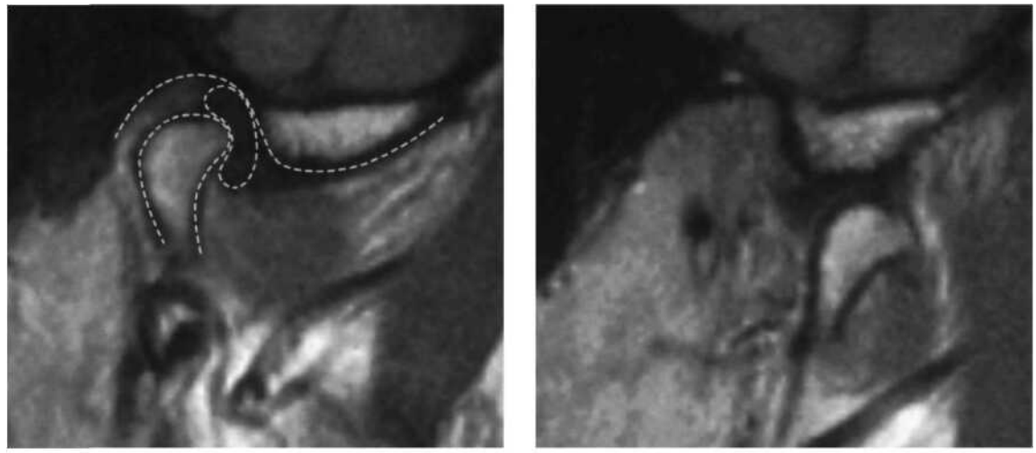
- With *condylar hypermobility,* there is always functional contact of the articular surfaces.
- In a case of *posterior disk displacement* there is no functional contact of the articular surfaces when the jaws are closed or open.
- In MRI, a *disk displacement during excursive movements* shows complete functional articular surface contact with the jaws closed, but this is lost when the jaws are opened.

This mechanism was first described by Klett (1982, 1985, 1986a,b) based upon electronic axiographic tracings. Later studies have demonstrated that axiographic tracings are not well suited for the differentiation of disk displacements (Parlett et al. 1993, Fushima 1994, Lund et al. 1995, Ozawa and Tanne 1997). So far only a few individual cases have been definitely confirmed throughout the world in MRI.

Partial disk displacement during excursive mandibular movement

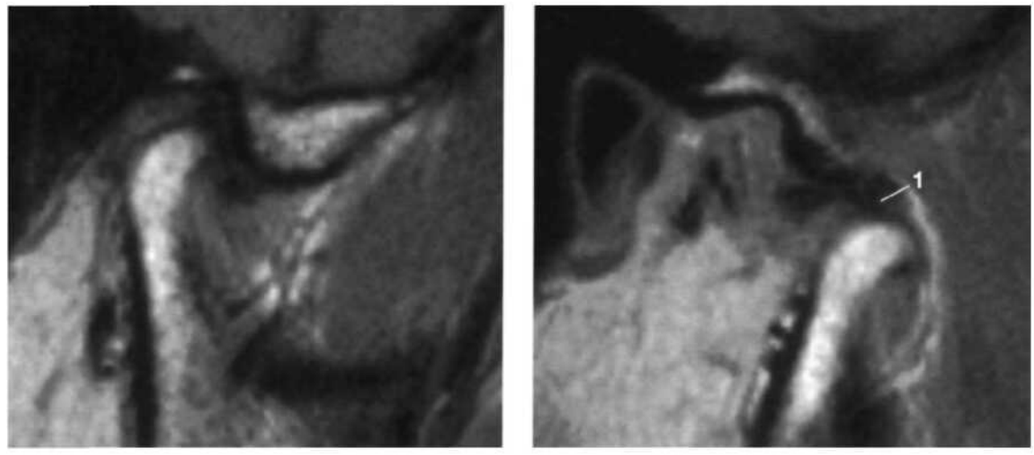
488 Medial slice
Left In habitual occlusion there is nothing remarkable about the relation between fossa, disk, and condyle (broken lines).

Right: At maximum jaw opening there is a small amount of condylar hypermobility. The disk is still in a physiological relation to the condyle, however.



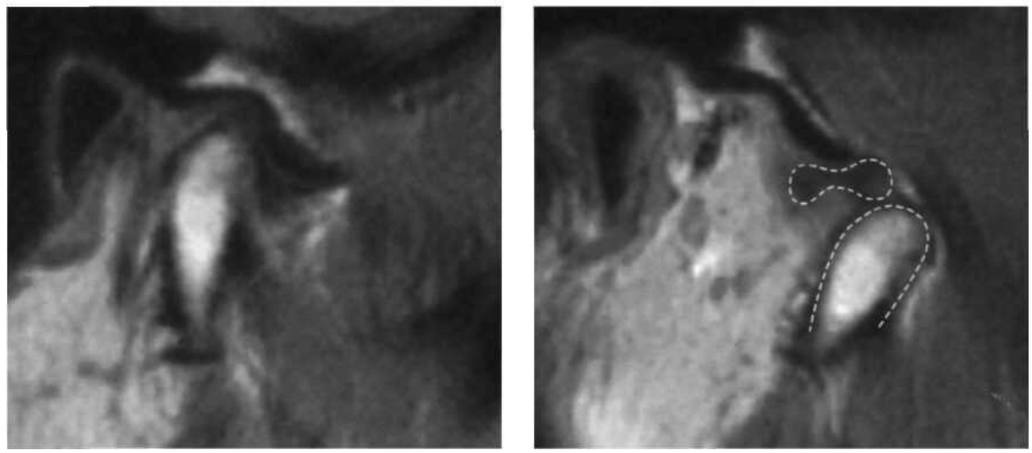
489 Central slice
Left: The central MRI slice at habitual occlusion likewise reveals nothing unusual.

Right: Because of condylar hypermobility and inadequate disk translation, the disk has become displaced by movement of the mandible to the maximally opened position. Functional articular surface contact has already been lost, but because the condyle is still in contact with the pars posterior (1) no clicking sound is present clinically.



490 Lateral slice
Left: There is nothing striking about this MRI made with the jaws closed.

Right: At maximum jaw opening, relationships similar to those in Figure 489 right are seen. However, the discrepancy between the functional joint surfaces is somewhat more pronounced (broken lines). Consideration of all the slices of this joint leads to a diagnosis of partial disk displacement during excursive mandibular movement.



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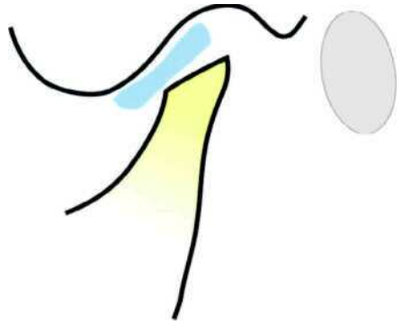
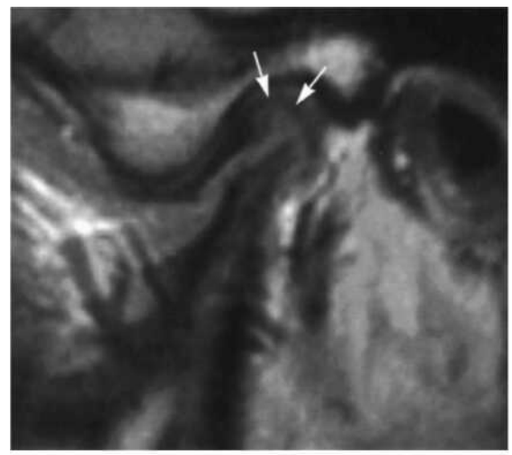
Regressive Adaptation of Bony Joint Structures

Osteoarthrosis is a degenerative functional disturbance of synovial joints that affects primarily the articular cartilage and the subchondral bone (Rasmussen 1983, Stegenga et al. 1992a). According to Boering (1994) the cause is overloading of the joint and/or reduced adaptability of the cartilage. Disk displacement is, like osteoarthrosis, presumably the *result of joint overloading* and not the cause of the degenerative changes (De Bont 1985, Stegenga et al. 1991). Lack of molar support or a condylar hypermobility does not necessarily lead to osteoarthrosis (Dijkstra et al. 1992, 1993; Holmlund and Axelsson 1994). Even though osteoarthrosis is frequently accompanied by deformation of the condyle that can be seen in the MRI and crepitus may be present, there is rarely any pain originating from the joint surfaces (de Leeuw et al. 1996). Changes in the joint surfaces cannot be detected clinically on MR images until they are well established. Elevated levels of interleukin-1 (IL-1) and matrix metalloproteinase-3 (MMP 3) in the synovial fluid appear to be a significant marker for early stages of degenerative changes in the articular surfaces (Kubota et al. 1997).



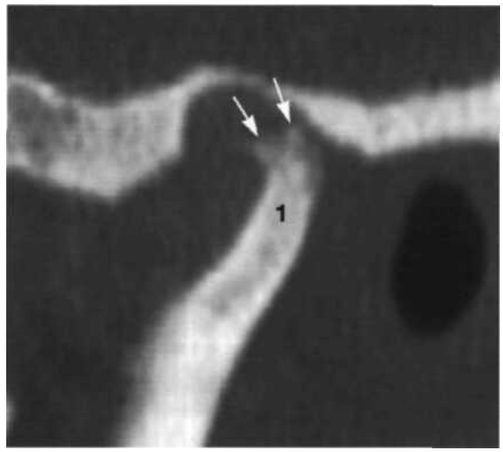


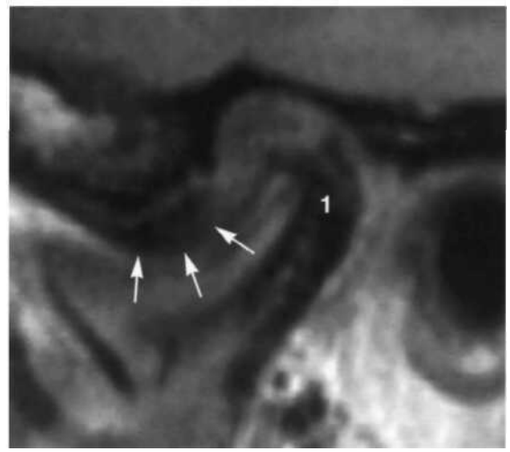
491 Osteoarthrosis of the condyle without disk displacement
Left: Illustration of the disk-condyle relation of a female patient with pronounced flattening of the left condyle but no significant disk displacement.

Right The MRI shows a straight-line flattening of the condyle without significant sclerosis (= normal thickness of the cortical plate). There is only minimal anterior displacement of the disk relative to the fossa. The bilaminar zone has undergone progressive adaptation (arrows).

492 Osteoarthrosis of the condyle with disk displacement
Left Illustration of the disk-condyle relationship in a female patient with osteoarthrotic deformation and disk displacement.

Right: The MRI clearly shows deformation of the condyle and a distinct sclerosis is seen here (= signal-poor, black structure). In this section the disk appears to be definitely displaced anteriorly. However, this could also be interpreted as a fibrosis of the anterior wall of the capsule (arrows).





493 Regressive adaptation of the condyle in an MRI and a CT scan
Left Until a few years ago, imaging of bony changes was still the domain of CT. This CT scan shows a condyle (1) positioned too far posteriorly relative to the fossa as well as osteoarthotic changes (arrows).

Right Identical information can be obtained with a modern MRI scan. In addition the MRI provides the clinician with information about the form and position of the disk (arrows).

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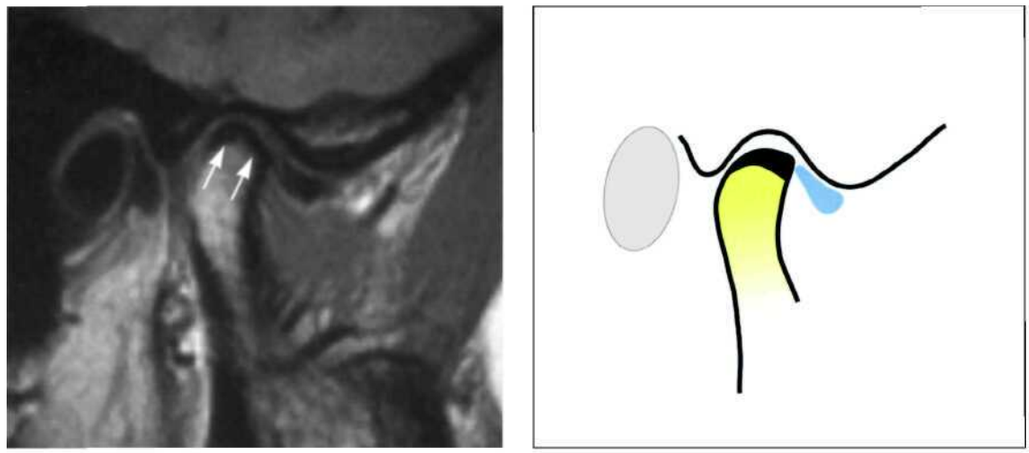
Progressive Adaptation of Bony Joint Structures

Contrary to its use in everyday speech, the term "progressive adaptation" as it relates to remodeling of the joint, does not mean a rapidly progressing resorption, but rather *an addition of bone in response to mechanical stimuli.* MRI is well suited not only for diagnosing functional adaptations in the temporomandibular joint, but also for detecting evidence of progressive adaptation following fractures of the neck of the condyle. MRI is superior to CT for this purpose because of its lack of ionizing radiation and its ability to reproduce soft tissues (Bumann et al. 1993, Takaku et al. 1996, Choi 1997, Oezmen et al. 1998). Because an intact disk-condyle complex is important for the restoration of function (Chuong 1995), MRI is useful in *determining whether conservative or surgical treatment* is indicated (Sullivan et al. 1997). It is also appropriate to use MRI for diagnosing progressive changes in the temporomandibular joint when employing new treatment methods such as *mandibular distraction osteogenesis* (Guerrero et al. 1997). Because of the adaptability of the joint structures, only minimal joint loading occurs during this latter treatment procedure (Harper et al. 1997).

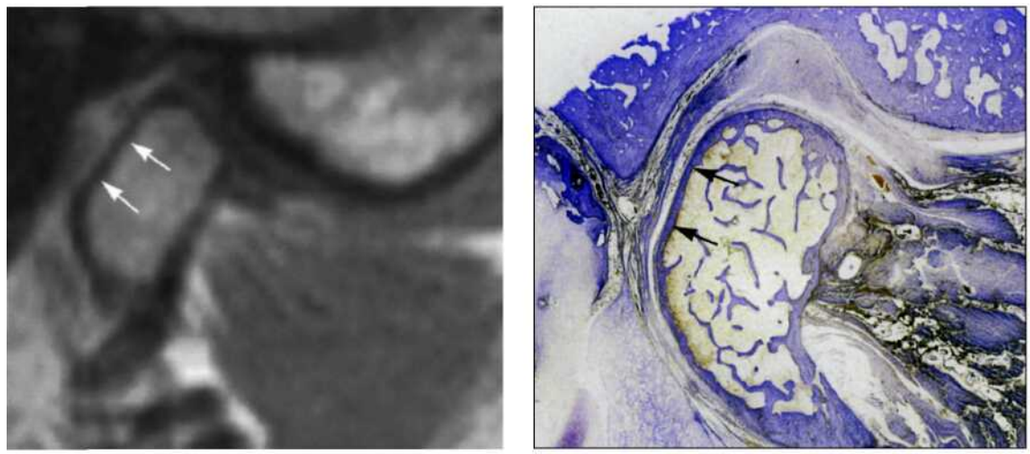
494 Adaptation of the superior surface of the condyle to functional joint compression
Left MRI showing thickening of the cortical bone (arrows) at the superior surface of the condyle in response to functional joint compression. Because the compact bone has relatively few protons it appears as a black, and in this case, thickened area. In addition, the disk is displaced anteriorly.

Right: Graphic illustration of the MRI findings.



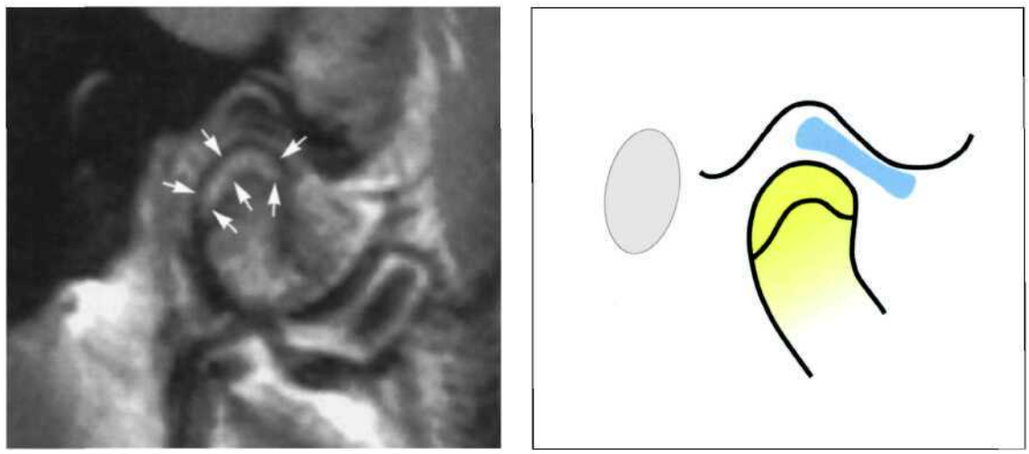
495 Posterior flattening of the condyle
Left: MRI with a more apparent flattening on the posterior surface of the condyle (arrows) in the presence of a retruded pattern of function. The compact bone at the posterior boundary of the joint has adapted to the increased retrusive function. Development of a flattened or concave surface on the condyle is evidence of an adaptation process (Hosoki et al. 1996).

Right: Similar situation in a histological preparation with adaptation of the bilaminarzone (arrows).



496 Progressive adaptation following fracture of the head of the condyle
Left: MRI one year after the head of the right condyle was fractured. The light area between the old and new compact bone (arrows) is the zone of progressive adaptation. With the latest high-resolution MR examination sequence, even the thickness of the cartilage can be reliably determined (Eckstein et al. 1998).

Right: Schematic drawing of the joint conditions with normal disk position.



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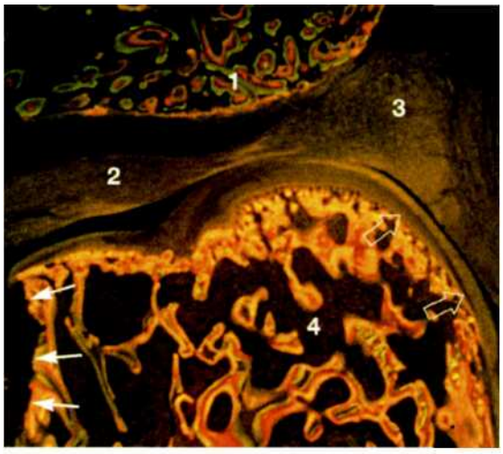
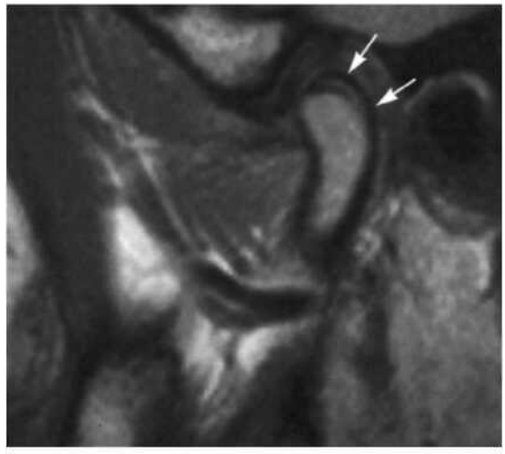
The capacity for progressive adaptation of bone structures in children and adolescents allows remodeling to occur in the temporomandibular joint during orthodontic treatment (Stockli and Willert 1971, Woodside et al. 1983,1987). Similar effects can be expected in young adults

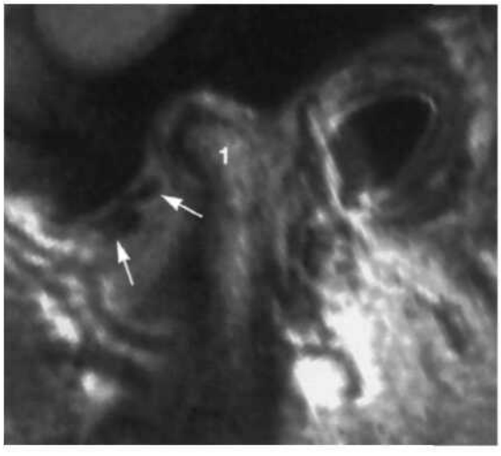
- after surgical repositioning of the condyles (Hoppenreijs et al. 1998),
- during long-term consistent wearing of an occlusal splint, or
- during treatment of a disk displacement without repositioning.

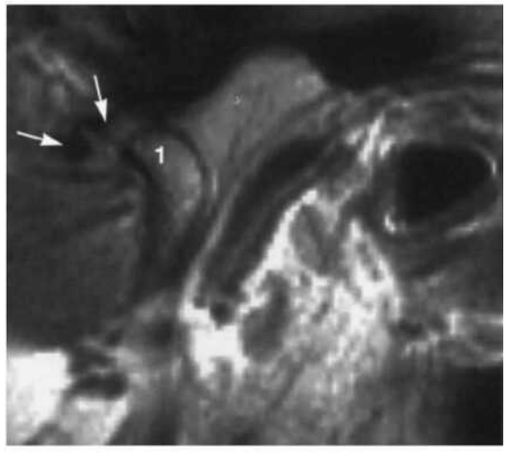
Progressive adaptation is possible in all directions, but is reversible. MRI findings indicate that in children aged 13-15 years, progressive adaptation of the fossa and condyle is completed within 3-6 months after insertion of a Herbst appliance (Bumann and Kaddah 1997). Other studies following the same design have confirmed this finding (Ruf and Pancherz 1998a, b). Relapse of orthodontic treatment leads to reverse adaptive processes. Furthermore, when there is a so-called *double occlusion* at the conclusion of orthodontic treatment (Egermark-Eriksson 1982), a stable mandibular position can become established in the more anterior position through progressive adaptation of the joint structures. This can be long-lasting if the functional conditions are favorable.





497 Posterosuperior adaptation
Left: Fluorescent microscopy after experimental surgical advancement of the mandible. At the top can be seen the articular eminence (1) and below it, the disk with its pars anterior (2) and pars posterior (3). The condyle (4) exhibits signs of progressive adaptation in its posterosuperior region. Anteriorly there lies a zone of resorption (arrows), and posterosuperiorly a new contour has formed (outlined arrows).
Collection of R Ewers
Right MRI showing double contours of the condyle (arrows) after long-term splint therapy.

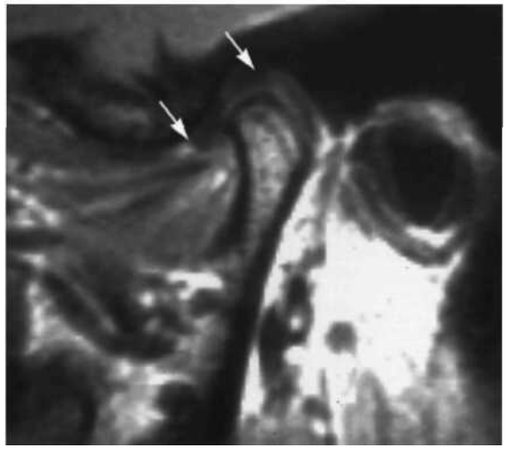




498 Anterior disk displacement, condition before condylotomy
Left: T1-weighted MRI with definite anterior disk displacement in habitual occlusion. The disk (arrows) lies far anterior to the condyle (1).

Right: With the jaws opened to the maximum extent the disk (arrows) is still situated anterior to the condyle (1) Accordingly, the condition is a disk displacement without repositioning.

Collection of D. *Hall* and *S.J. Cibbs* (Figs. 498, 499)



499 Progressive adaptation after condylotomy
Left: T1-weighted MRI of the same patient as in Figure 498 1 day after surgical advancement of the condyle (Werther et al. 1995, McKenna et al. 1996). While the disk has not been perfectly repositioned, the pars posterior (2) does lie over the condyle (1) once more.

Right: 2.5 years after the operation a normal disk-condyle relationship has been formed through progressive adaptation. The arrows mark the position of the disk.

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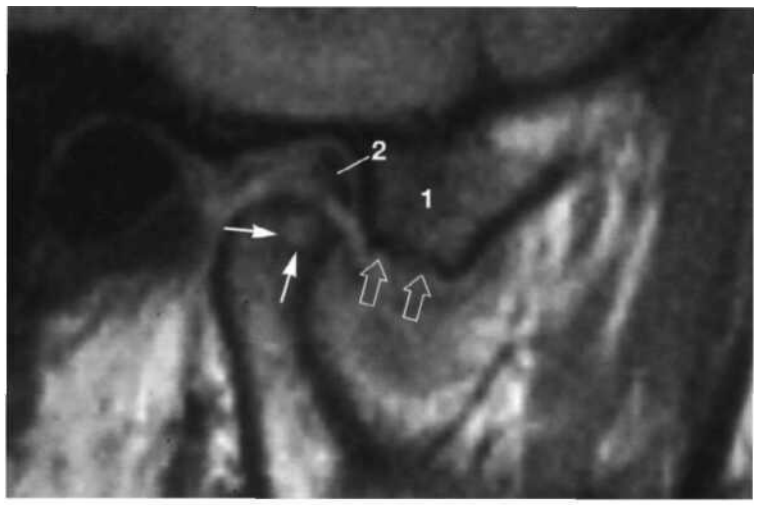
Evaluation of Adaptive Changes: MRI Versus CT

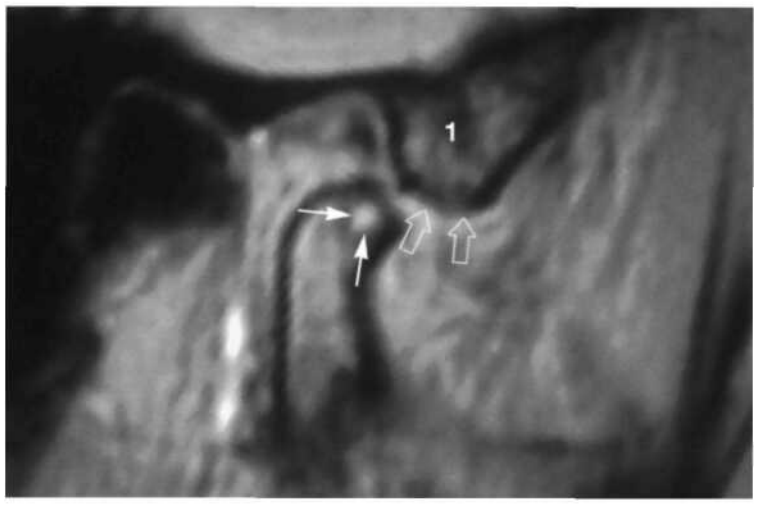
Osseous changes in the temporomandibular joint can often be demonstrated through imaging procedures when there is no report of pain (Tyndall et al. 1995, de Leeuw et al. 1996). While MRI is the method of choice for determining the disk position (Liedberg et al. 1996), frequently CT is still preferred for recording changes in bone. With the systematic application of Tl- and T2-weighted images from modern MR scanners, however, MRI is not inferior to CT in the evaluation of bony structures. The detection of joint effusion in MRI supports the diagnosis of active degenerative processes (Adame et al. 1998). Injection of liposome-bound contrast medium (Griinder et al. 1998) even makes it possible to identify initial degenerative changes in cartilage.

Still earlier stages of cartilaginous changes can be diagnosed only through chromatographic analysis of the synovial fluid. More recent studies indicate that interleukin-1 and the relative proportions of chondroitin-6 sulfate and chondroitin-4 sulfate are reliable markers of joint pathology (Murakami et al. 1998, Shibata et al. 1998).

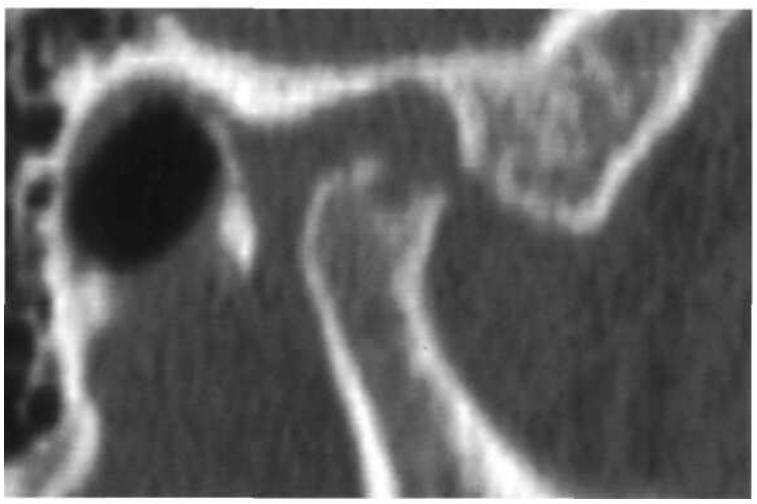
500 Osteoarthrosis in Tl - weighted MRI
MRI in habitual occlusion. The patient is a 38-year-old female with osteoarthrosis and a subchondral cyst in the right temporomandibular joint. The articular eminence (1) shows degenerative flattening of the subchondral bone structure (outlined arrows). With the T1-weighting.thereisonlya hint ofthe subchondral cyst (arrows). The disk cannot be clearly defined, but the signal-poor structure (2) in the fossa could be part of the pars posterior.



501 Osteoarthrosis in T2-weighted MRI
The routinely used T2-weighting at maximum jaw opening makes the subchondral cyst (arrows) clearly visible because of its intense signal due to its proton-rich content. As already suspected from the closed-jaw scan, the degenerative change in the subchondral bone of the articular eminence (1) is covered by a layer of soft tissue (outlined arrows). The disk still cannot be delineated. These finding were confirmed during surgery.



502 Osteoarthrosis in a CT scan
While a CT of the same joint does represent an exact image of the bone structure, it provides no new information beyond that found in the T1- and T2-weighted MRI. An additional consideration is that MRI does not subject the patient to any ionizing radiation. However, until the MRI can routinely provide reliable three-dimensional reconstructions, CT is still indicated for planning surgical procedures on the bony structures of the temporomandibular joint.



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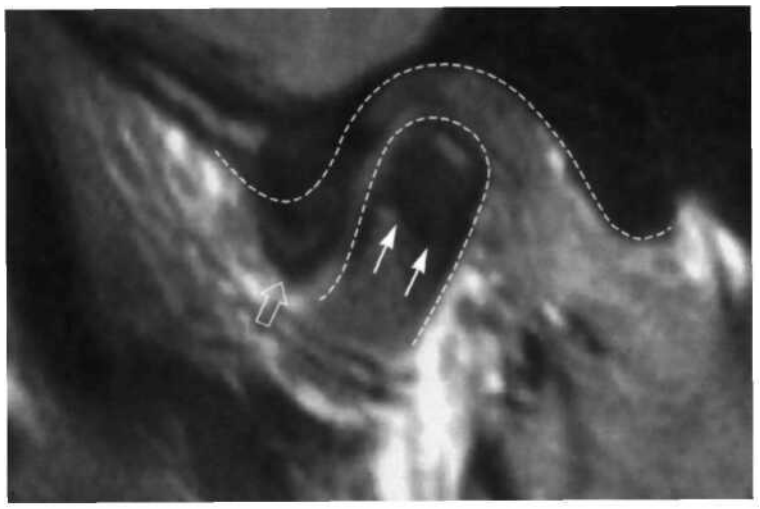
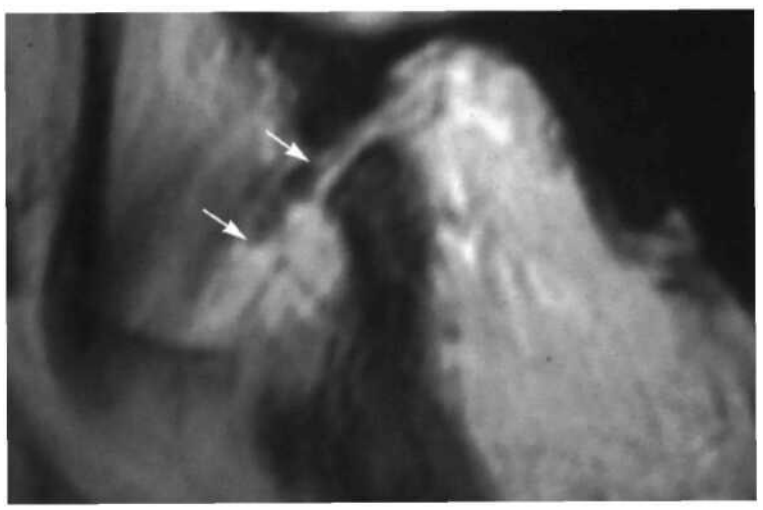
Avascular Necrosis Versus Osteoarthrosis

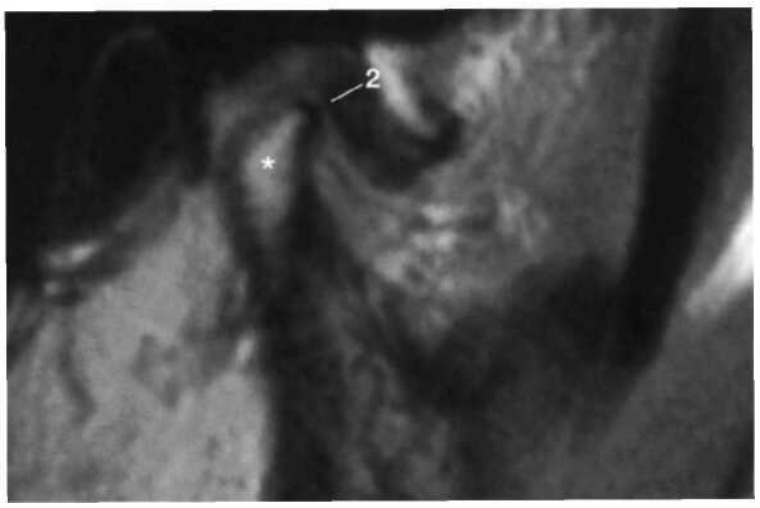
Avascular necrosis is a necrosis of subchondral bone and bone marrow resulting from a reduced blood supply. It may be associated with free joint bodies (Ercoli et al. 1998). Anterior disk displacements, mandibular osteotomies, and diskectomies are thought to be primary causes or predisposing factors (Schellhas et al. 1992). This has been contested, however (Piper 1989, Schellhas et al. 1989 b, White et al. 1991, Chuong and Piper 1993, Hatcher et al. 1997, Hardy et al. 1998). The signal intensity of the bone marrow within the condyle can provide evidence of edema (hypointense with Tl-weighting and hyperintense with T2-weighting) or sclerosis (hypointense with Tl- and T2-weighting) (Mitchell et al. 1987, Schellhas et al. 1989a). The incidence of bone marrow sclerosis in the temporomandibular joint is between 13 and 3% (Lieberman et al. 1996, Hatcher 1997, Bumann et al. 1999). Avascular necrosis, however, is indicated only by the combination of sclerosis and intact contours of the joint surfaces (incidence <0.3%). Sclerosis with degenerative changes in the articulating surfaces does not necessarily point to an avascular necrosis, because these findings can also occur with Osteoarthrosis.



503 Avascular necrosis in Tl-weighted MRI
Left temporomandibular joint of a 12-year-old female patient. The contours of the condyle and fossa are outlined with broken lines. The condyle shows a large signal-poor area (arrows). The contour of the articulating surface of the condyle has not undergone significant degenerative changes. The disk (outlined arrows) is displaced anteriorly. Because of the adaptation in the bilaminar zone and the anterior wall of the capsule, the pars anterior and pars posterior cannot be accurately defined.



504 Avascular necrosis in T2-weighted MRI
Additional MRI of the joint at maximum jaw opening provides further information. The condyle is again represented by a signal-poor image—evidence of sclerosis of the bone marrow. While the condyle is slightly flattened, its contours reflect no significant degenerative changes. With the jaws open, the disk (arrows) still lies anterior to the condyle (= disk displacement without repositioning).



505 Tl-weighted MRI of the contralateral condyle
The contralateral joint should always be examined as well for comparison. With the jaws closed, the signal intensity from the bone marrow of the right condyle (*) is normal. The disk displays a tendency for anterior disk displacement. The pars posterior (1) still lies on the condyle, however. Clinically, there are no symptoms on the right side, but on the left side, pain can be reproducibly provoked by posterior compression.

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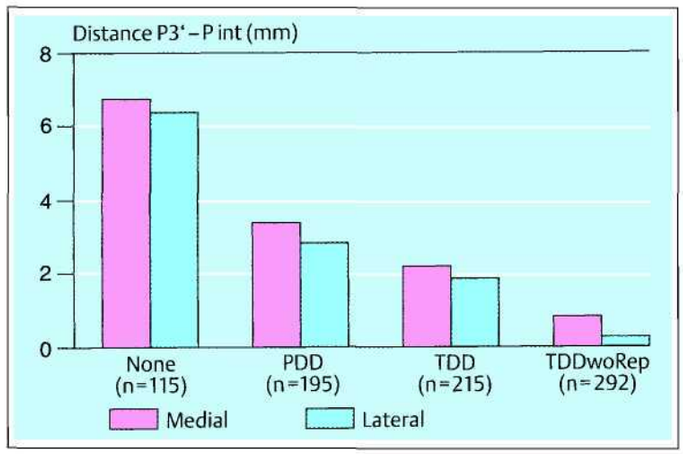
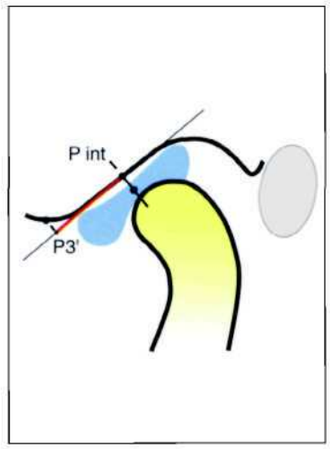
Metric (Quantitative) MRI Analysis

Visual evaluation of MR images is indeed quick and the actual anatomical situation is reliably reproduced. Nevertheless, visual evaluation alone is not enough to support conclusions concerning the relation between fossa, disk, and condyle. Therefore metric MRI analysis, comparable to cephalometric analysis of lateral transcranial radiographs, was developed (Davant et al. 1993, Bumann et al. 1996). This makes it possible to accurately describe the joint conditions just before orthodontic treatment and to document the effects of treatment on the temporomandibular joint (Bumann and Kaddah 1997).

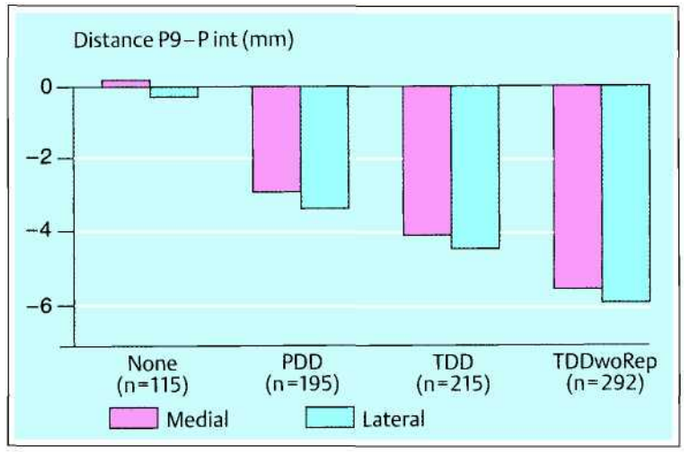
In this analysis method 31 reference points are digitalized by means of special computer software (FR-WIN 5.0, Computer Konkret). From these data, 51 variables are determined. For practical application, eight reliable parameters that determine metrically the relationships among fossa, disk, and condyle are selected from among these and arranged in an "MRI box" for a clear overview (Bumann et al. 1997).

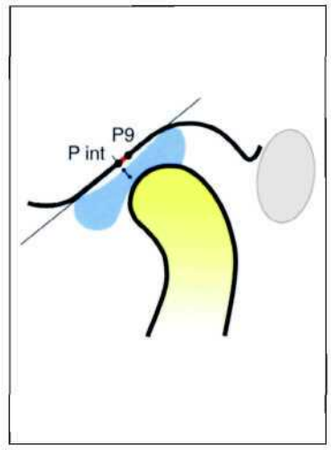
506 Position of the disk relative to the fossa
Average values of the distance **P3'-P int** with different degrees of disk displacement (DD): PDD = partial DD; TDD = total DD; **TDDwoRep** = total DD without repositioning.
For better comparison of values, measurements were made after projecting the reference points onto a line tangent to the protuberance. **P3'-P int** (red line in the drawing to the right) describes the position of the articular disk relative to the glenoid fossa. The smaller this distance, the more the disk is displaced anteriorly.



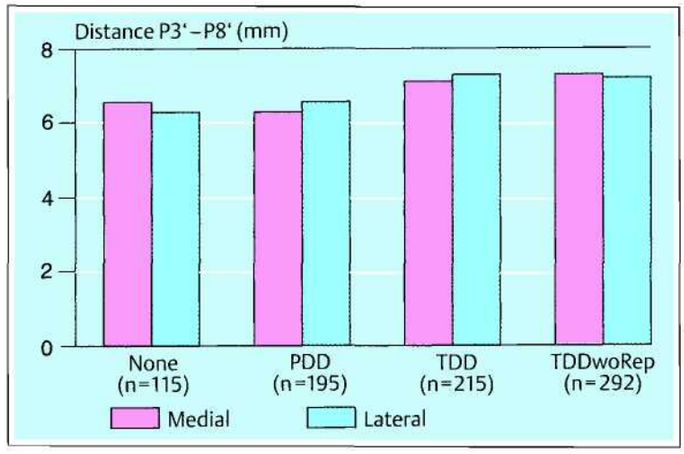


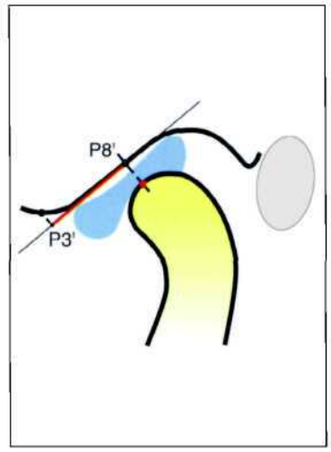
507 Position of the disk relative to the fossa
Average values of the distance **P9-P int** for different degrees of disk displacement. (See Fig. 506 for abbreviations.) This distance (red in the picture to the right) between the turning point (= change in curvature) **P9** on the protuberance and point P int at the level of the pars intermedia of the disk likewise define the position of the articulating disk to the glenoid fossa. In the ideal case this distance would be 0. Increasing negative values indicate increasing anterior disk displacement.





508 Position of the condyle relative to the fossa
Average values for the distance **P3'-P8'** with different degrees of disk displacement. (See Fig. 506 for abbreviations.) The point **P8** lies at the level of the most anterosuperior curvature of the condyle (red dot in the picture to the right). **P3'-P8'** (red line) describes the position of the condyle relative to the fossa. The longer this distance, the more the condyle is displaced distally. In contrast to **P3'-P int** and **P9-P int, P3'-P8'** is independent of the degree of disk displacement.





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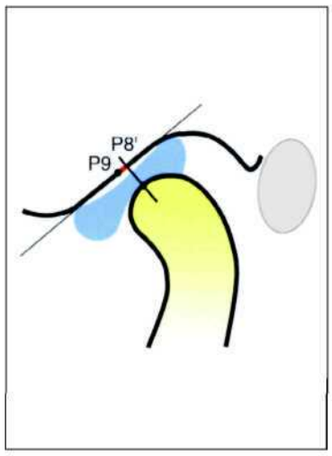
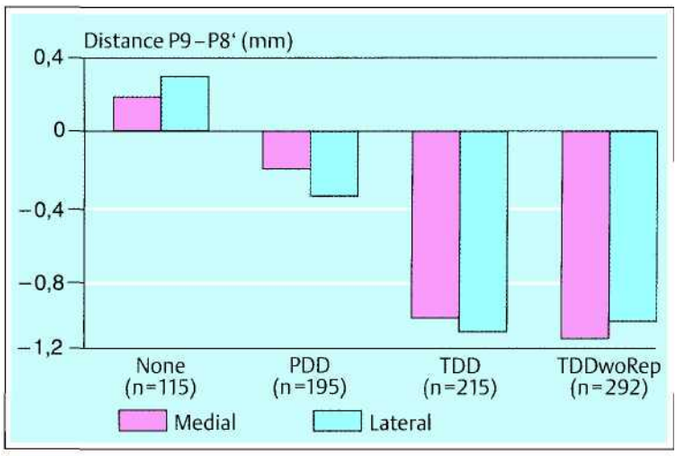
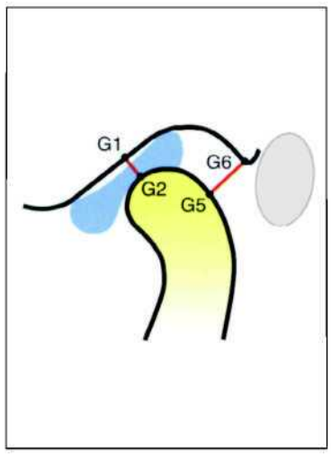
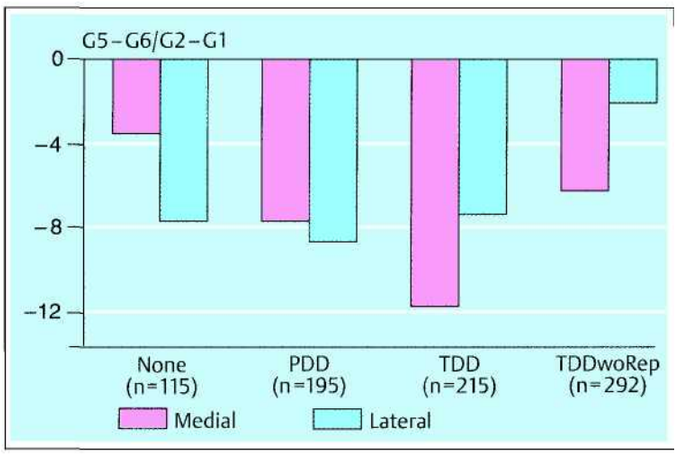


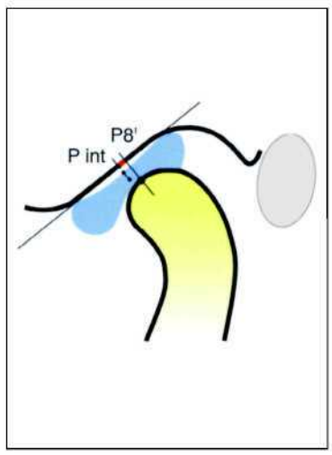


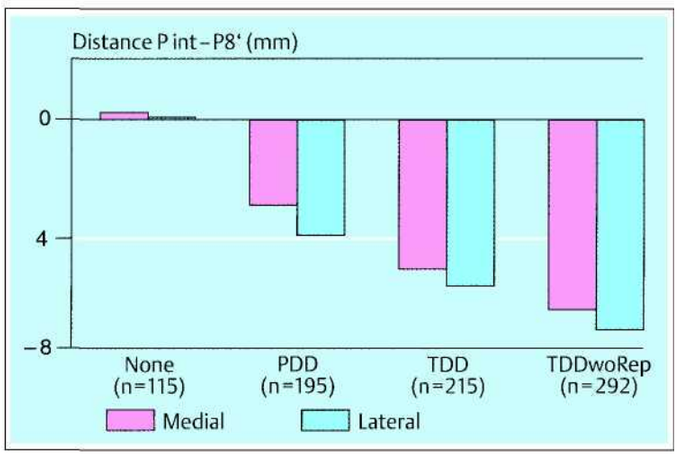
509 Position of the condyle relative to the fossa
Average values for the distance **P9-P8'** at different degrees of disk displacement. (See Fig. 506 for abbreviations.) The distance (red line in the *left-hand* picture) between the turning-point P9 and the most anterosuperior contour of the condyle (P8) is a measurement of the condyle's position relative to the fossa. According to our studies on a large number of patients, it does vary with the degree of disk displacement.



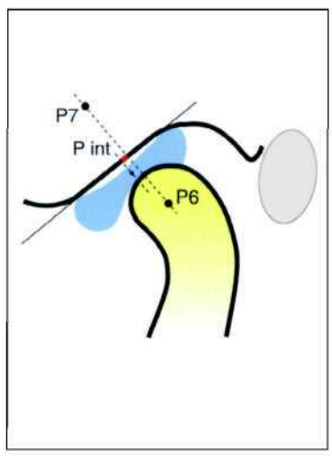


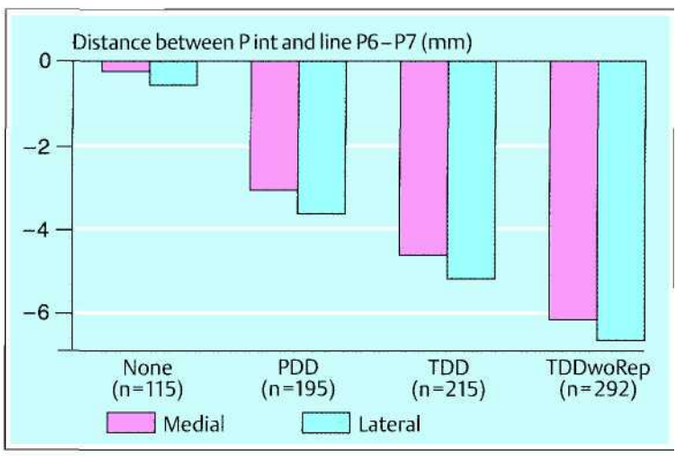
510 Position of the condyle relative to the fossa
Average values for the quotients of the widths of the anterior **(G5-G6)** and the posterior (G2-G1) parts of the joint space (after Pullinger and Hollender 1985) as they relate to the degree of disk displacement. (See Fig. 506 for abbreviations.) This quotient is likewise a quantitative measurement for the position of the condyle in the fossa *(left)*. It does not vary directly with the degree of disk displacement.





511 Position of the disk relative to the condyle
Average values for the distance **P int-P8'** for different degrees of disk displacement. (See Fig. 506 for abbreviations.) The distance (red line in *left* drawing) between point P int at the level of the pars intermedia and P8 at the most anterosuperior part of the condyle describes the relation between disk and condyle. Ideally the distance should equal 0. Negative values represent an anterior disk displacement relative to the condyle.





512 Position of the disk relative to the condyle
Average values for the distance (red line in *left* drawing) between point P int and a line connecting the centers of the condyle (P6) and the eminence (P7) for different degrees of disk displacement. (See Fig. 506 for abbreviations.) This distance can determine the functional disk-condyle relationship. Negative values indicate an anterior disk displacement relative to the condyle.

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Examples of Bumann's MRI Analysis

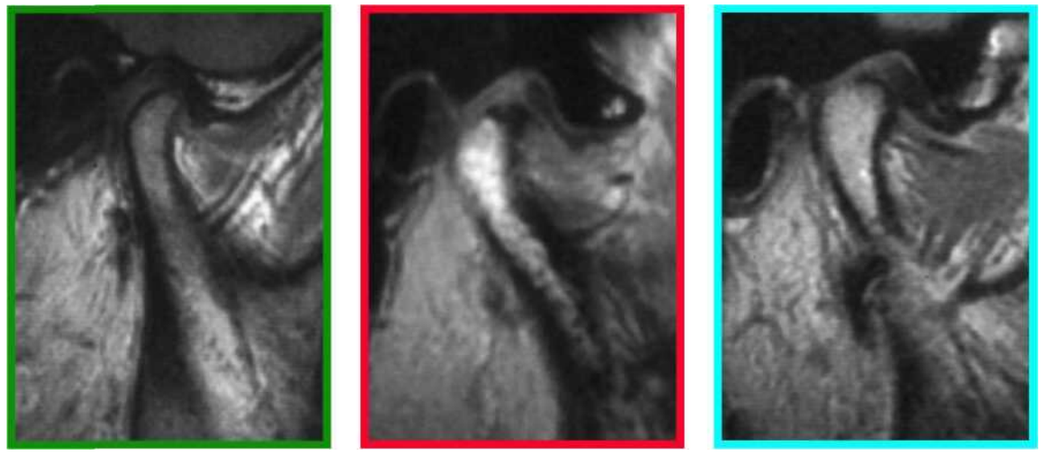
The seven parameters described on pages 109f and the variable referred to as "disk position with jaws open," which is determined by the position of the disk relative to the line connecting P6 and P7 (designated as 07/08 with the jaws open), are arranged together in a so-called MRI box (Fig. 514) (Bumann et al. 1997). The sections of the box with gray backgrounds include the normal biological ranges. Measurements that fall above the gray areas represent relative anterior disk displacements, and those falling below represent relative posterior displacements. The eight parameters describe the disk position relative to the fossa, the condylar position relative to the fossa, the disk position relative to the condyle, and the disk position with the jaws open. This procedure makes it possible for the first time to quantitatively classify discrepancies in the disk-condyle relationship according to their causes. Here it is possible that

- the disk is in the correct position and the condyle is displaced posteriorly,
- the condyle is in the correct position and the disk is totally displaced anteriorly, or
- there is a combination of both conditions.

513 Disk-condyle relationships
Left: Normal relationship in the right temporomandibular joint of a 28-year-old man.

Center: Anterior disk displacement (DD) with the fault in the condyle. In this 54-year-old woman the position of the disk is nearly correct but the condyle is too far posterior.

Right: Anterior DD through a combination of posterior malposition of the condyle and absolute anterior DD in a 30-year-old man.



514 MRI analysis of a healthy temporomandibular joint
Measurements for evaluating the joint shown in Figure 513 left. All the measurements (underlined in green) lie within the normal ranges indicated by the gray background. This is an ideal situation to have before and/or after dental treatment. If the static positional relationships are outside the normal range, it should be determined through manual functional analysis whether all structures are fully adapted in the direction of the deviation. It is not necessary to treat every deviation.

Disk to fossa		Condyle to fossa			Disk to condyle		Position (jaws open)
P3'-Pint	P9-Pint	P3'-P8'	P9-P8[1]	Anterior/posterior	P8'-Pint	P6/P7-Pint	to O7-O8
-0.4	-3.9	-1.3	+6.1	+ 74.7	-4.7	-4.5	+190.1
+0.8	-3.2	+0.0	+5.1	+ 61.3	-3.9	-3.8	+174.7
+2.0	-2.5	+1.3	+4.1	+ 47.9	-3.1	-3.1	+159.3
+3.2	-1.8	+2.6	+3.1	+ 34.5	-2.3	-2.4	+143.9
+4.4	-1.1	+3.9	+2.1	+21.1	-1.5	-1.7	+126.5
+5.6	-0.4	+5.2	+1.1	+ 7.7	-0.7	-1.0	+113.1
+6.8	+0.3	+6.5	+0.1	-5.7	+0.1	-0.3	+ 97.7
+8.0	+1.0	+7.8	-0.9	-19.1	+0.9	+0.4	+ 82.3
+9.2	+1.7	+9.1	-1.9	-32.5	+1.7	+1.1	+ 66.9
+10.4	+2.4	+10.4	-2.9	-45.9	+2.5	+1.8	+ 51.3
+11.6	+3.1	+11.7	-3.9	-59.3	+3.3	+2.5	+ 36.1
+12.8	+3.8	+13.0	-4.9	-72.7	+4.1	+3.2	+ 20.1
+14.0	+4.5	+14.3	-5.9	-86.1	+4.9	+3.9	+ 5.3

515 MRI analysis with anterior disk displacement
Measurements for evaluation of the joints in Figure 513 center (red) and 513 right (blue). The values for the position of the "disk relative to the condyle" are above the norm for both joints (= indicating anterior displacement). In Figure 513 center, the disk to fossa relationship is just on the borderline of the normal range but the condyle is definitely displaced posteriorly. This leads to the diagnosis "disk displacement with the fault in the condyle." In Figure 513 right (blue) the disk is displaced anteriorly and the condyle is displaced posteriorly.

Disk to fossa		Condyle to fossa			Disk to condyle		Position (jaws open)
P3'-Pint	P9-Pint	P3'-P8'	P9-P8[1]	Anterior/posterior	PS'- Pint	P6/P7-Pint	toO7-O8
-0.4	-3.9	-1.3	+6.1	+74.7	-4.7	-4.5	+190.1
+ 0.8	-3.2	+ 0.0	+5.1	+ 61.3	-Mi	-*»	+174.7
	-2.5	+ 1.3	+4.1	+ 47.9	-3.1	-3.1	+159.3
+ 3.2		+ 2.6	+3.1	+34.5	^Mi	-2.4	+143.9
	-1.1	+ 3.9	+2.1	+21.1	-1.5	-1.7	+126.5
+ 5.6	-0.4	+ 5.2	+1.1	+ 7.7	-0.7	-1.0	+113.1
+ 6.8	+0.3	+ 6.5	+0.1	-5.7	+0.1	-0.3	S3S
+ 8.0	+1.0	+ 7.8		-19.1	+0.9	+0.4	+ 82.3
+ 9.2	+1.7		2£	32 5	+1.7	+1.1	+ 66.9
+10.4	+2.4	+10.4	-2.9	-45.9	+2.5	+1.8	+ 51.3
+ 11.6	+3.1	+11.7	-3.9	-59.3	+3.3	+2.5	+ 36.1
+12.8	+3.8	+13.0	-4.9	-5S	+4.1	+3.2	+ 20.1
+14.0	+4.5	+14.3	-5.9	-86.1	+4.9	+3.9	+ 5.3

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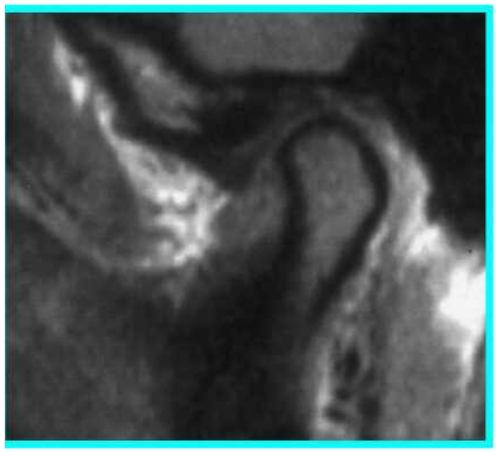
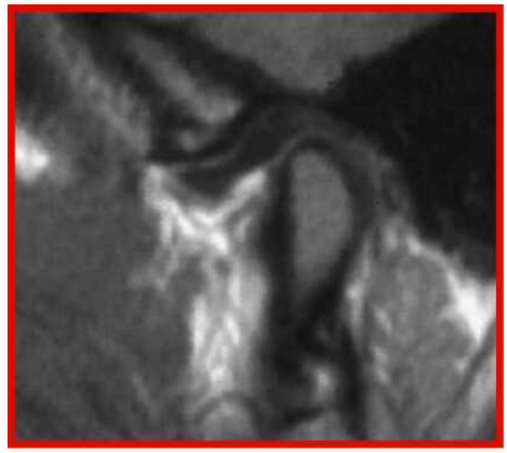


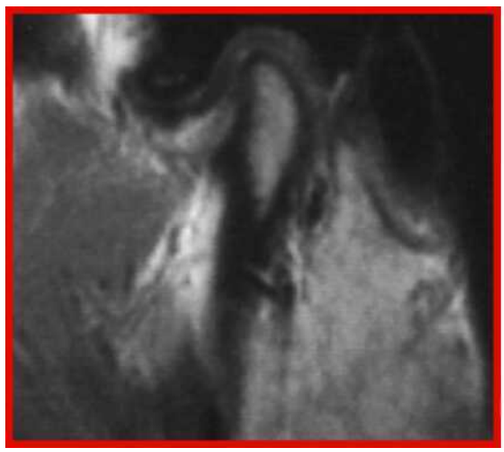


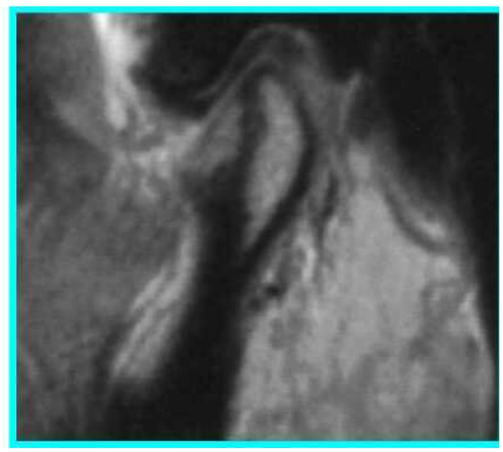
516 MRI of a partial disk displacement
Left: An almost normal disk-condyle relationship in a 26-year-old female is seen in the medial portion of the joint with the teeth in habitual occlusion.

Right: The lateral portion of the same joint in habitual occlusion. Here the disk lies distinctly anterior to the condyle. An overall evaluation of both MRI slices leads to the diagnosis "partial disk displacement."

Disk to fossa		Condyle to fossa			Disk to condyle		Position (jaws open)
P3'-Pint	P9-Pint	P3'-P8'	P9-P8'	Anterior/posterior	P8'-Pint	P6/P7-Pint	to O7-O8
-0.4	ST?	-1.3	+6.1	+74.7	-4.7	-4.5	+190.1
+ 0.8	-3.2	+ 0.0	+5.1	+61.3	-3.9	-3.8	+174.7
+ 2.0	-2.5	+ 1.3	+4.1	+47.9	-3.1	-3.1	+159.3
+ 3.2	-1.8	+ 2.6	+3.1	+34.5	-2.3	-2.4	+143.9
+ 4.4		+ 3.9		+ 21.1	-1.5	-1.7	+126.5
+ 5.6	-0.4	+ 5*	+1.1	+ 7.7	-0.7	-1.0	
+ 6.8	+0.3	+ 6.5	+0.1	-5.7	+0.1	-0.3	
+ 8.0	+1.0	+ 7.8		-19.1	+0.9	+0.4	+ 82.3
+ 9.2	+1.7	+ 9.1	-1.9	-32.5	+1.7	+1.1	+ 66.9
+10.4	+2.4	+10.4	-2.9		+2.5	+1.8	+ 51.3
+11.6	+3.1	+11.7	-3.9	-59.3	+3.3	+2.5	+ 36.1
+12.8	+3.8	+13.0	-4.9	-72.7	+4.1	+3.2	+ 20.1
+14.0	+4.5	+14.3	-5.9	-86.1	+4.9	+3.9	+ 5.3

517 MRI analysis with partial disk displacement
The values for the medial portion of the joint (blue) from Figure 516 left all fall within the normal range. In the lateral portion of the joint (red) the disk lies anterior to the fossa (= values above the norm). In the lateral portion the condyle clearly lies farther posterior—a relatively common finding in MRI analyses of partial disk displacements. During jaw opening (position relative to O7-08) the disk becomes repositioned so that the values for both slices fall within the normal range.





518 Disk displacement with repositioning by means of an occlusal splint
Left MRI showing the disk-condyle relationship in habitual occlusion in the medial portion of the joint of *a* 23-year-old male. The disk clearly lies in front of the condyle and the bilaminar zone is adapted.

Right: MRI of the disk-condyle relationship in the therapeutic mandibular position after insertion of an occlusal splint. The disk again lies over the condyle, and the condyle is more anteriorly positioned within the fossa than it was in the initial findings.

Disk to fossa		Condyle to fossa			Disk to condyle		Position (jaws open)
P3'-Pint	P9-Pint	P3-P8[1]	P9-P8[1]	Anterior/posterior	P8'-Pint	P6/P7-Pint	to O7-08
-0.4	-3.9	-1.3	+6.1	+74.7	-4.7	-4.5	+190.1
	-3.2	+ 0.0	+5.1	+61.3	-3.9	-3.8	+174.7
+ 2.0	-2.5	+ 1.3	+4.1	+47.9	-3.1	-3.1	+159.3
+ 3.2	-1.8	+ 2.6	+3.1	+34.5	-2.3	-2.4	+143.9
+ 4.4		+ 3.9			-1.5	-1.7	+126.5
	-0.4		+1.1	+ 7.7	-0.7	-1.0	
+ 6.8	+0.3			-5.7			
+ 8.0	+1.0	+ 7.8	-0.9	-19.1	+0.9	+0.4	+ 82.3
+ 9.2	+1.7	+ 9.1	-1.9	-32.5	+1.7	+1.1	+ 66.9
+10.4	+2.4	+10.4	-2.9	-45.9	+2.5	+1.8	+ 51.3
+11.6	+3.1	+11.7	-3.9	-59.3	+3.3	+2.5	+ 36.1
+12.8	+3.8	+13.0	-4.9	-72.7	+4.1	+3.2	+ 20.1
+14.0	+4.5	+14.3	-5.9	-86.1	+4.9	+3.9	+ 5.3

519 MRI analysis with disk repositioned by an occlusal splint
Evaluation of the pretreatment situation (red) shows clearly that this slice reveals an anterior disk displacement with the fault in the disk. This is an unfavorable condition, because only the position of the condyle can be influenced by the treatment. In this case, however, the disk position was successfully normalized with an occlusal splint without moving the condylar position out of the normal range, even though it was definitely repositioned anteriorly (blue).

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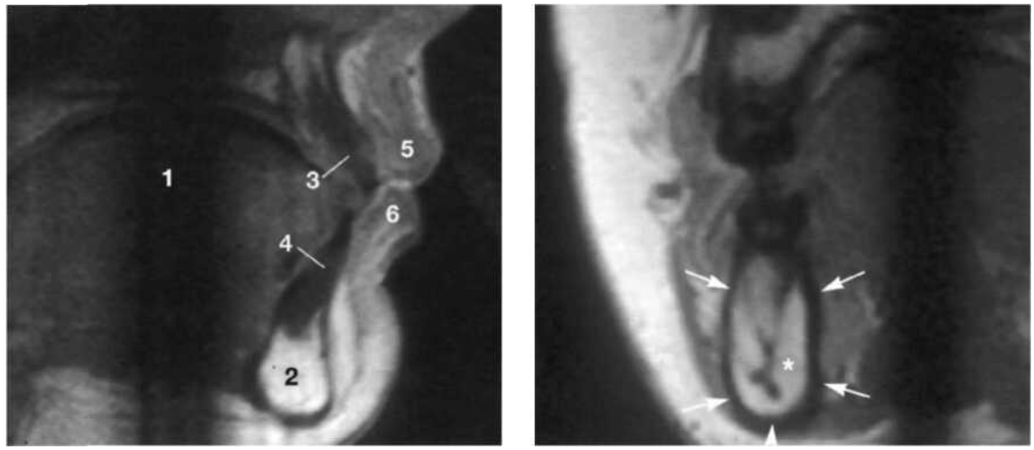
MRI for Orthodontic Questions

We have described how MRI is useful for visualization of the positional relationships among fossa, disk, and condyle (Bumann et al. 1993, Katzberg et al. 1996) and for monitoring of remodeling processes in the TMJ during and after orthodontic treatment (Bumann and Kaddah 1997, Foucart et al. 1998). Other indications for MRI in orthodontics:

- MRI can be used as an alternative to CT for determining the amount of labial and lingual bone available prior to planned tooth movement. At present, though, CT still has the clear advantage in accurately classifying intra-alveolar bone pockets (Langen et al. 1995).
- It can be used for diagnosing abnormalities in the tongue (Lauder and Muhl 1991, Yoo et al. 1996), evaluating muscle mass in cross-section (van Spronsen et al. 1996), and determining vectors of the muscles of mastication in developmental disturbances of the facial bones (van Spronsen et al. 1997).
- As an alternative to CT for assessing resorption of lateral incisor roots by retained canines (Ericson and Kurol 1987).
- It is a valuable aid in examining patients with cleft lip and palate (Naito et al. 1986, Joos and Friedburg 1987, McGowan et al. 1992, Yamawaki et al. 1996).

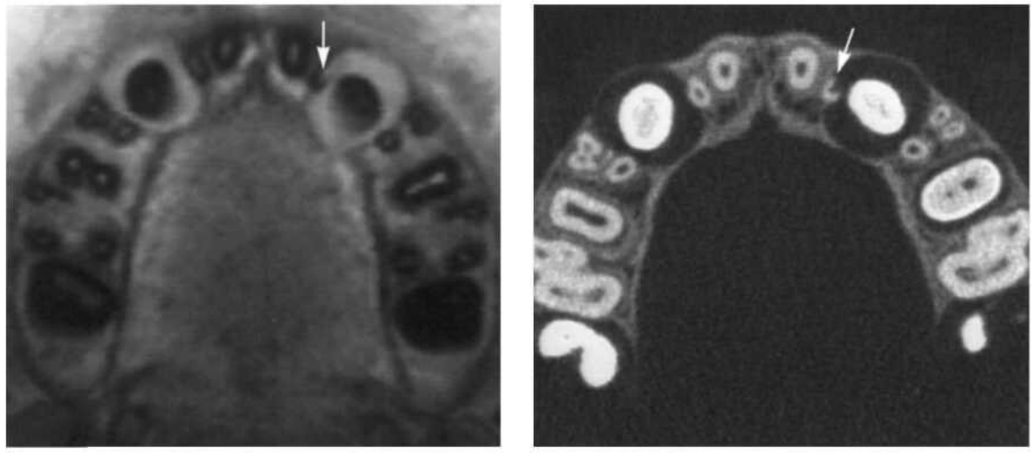
520 Evaluation of available bone mass
Left: Sagittal MRI showing the tongue (1), mandibular symphysis (2), incisor teeth (3, 4) and the lips (5, 6). Resolution and reproduction of detail still do not measure up to the CT standard, but nevertheless, the amount of bone available can be evaluated thoroughly.

Right: MRI of the lower right first molar in the frontal plane. It clearly shows not only the compact bone (arrows) but also the connection with the inferior alveolar nerve (*).



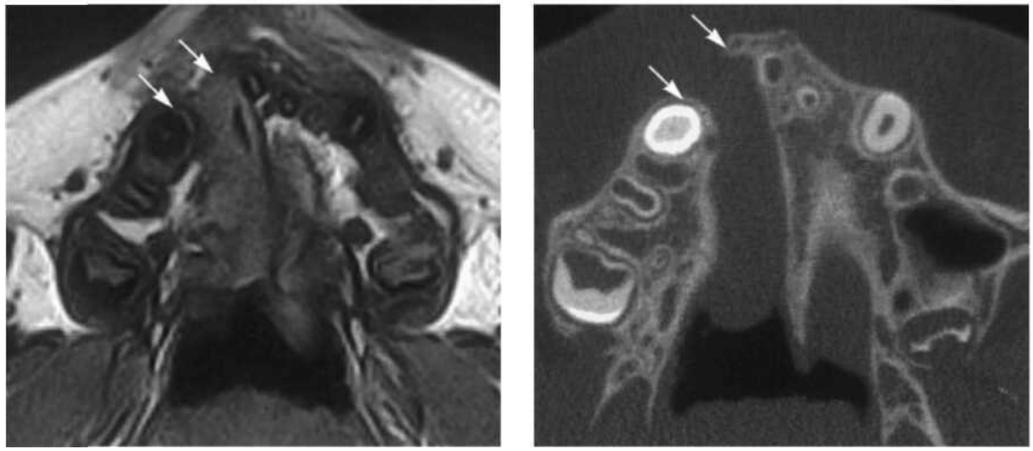
521 Evidence of root resorption
Left: MRI of the maxilla of a 13-year-old boy in the horizontal plane. The retained upper right canine or its follicle has caused root resorption on the distal surface of the lateral incisor (arrow).

Right: CT image of the same maxillary region. Although the resolution is better here, the use of ionizing radiation did not provide any new diagnostic information. The resorption (arrow) appears the same.



522 Supplemental diagnostic tool for cleft lip and palate
Left: MRI of a unilateral complete cleft of the lip and palate on the left side (arrows). With MRI one can evaluate not only the boundaries of the bone, but also the characteristics of the soft tissue.

Right: CT scan showing the same cleft (arrows). While it is true that the bone contours are depicted more sharply, otherwise there is no additional diagnostic advantage.



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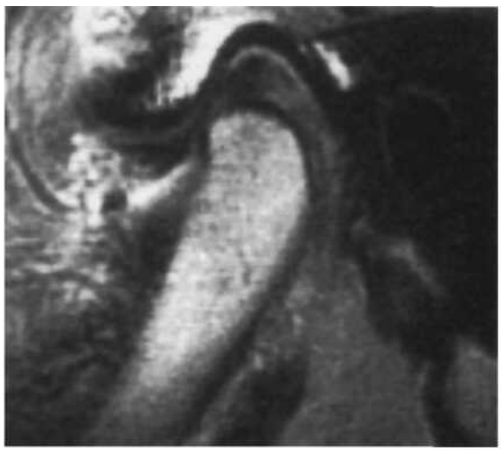
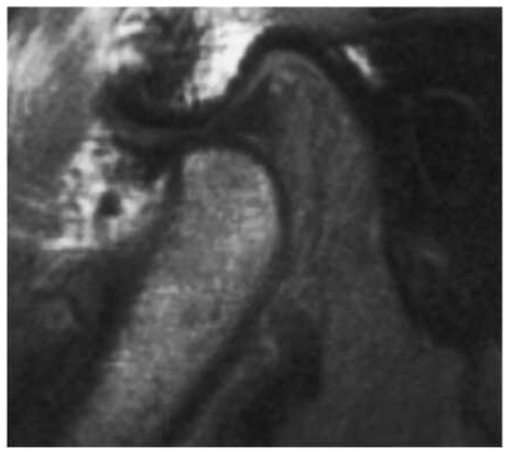
Three-Dimensional Imaging with MRI Data

For the past several years it has been possible to create a three-dimensional image of the temporomandibular joint from MRI data on a computer monitor by using special software (Price et al. 1992, Krebs et al. 1995). For evaluation of disk displacements, a three-dimensional reconstruction is superior to an isolated sagittal slice in the SE technique, but the combined evaluation of two-dimensional sagittal and coronal slices is equally valuable (Yamada et al. 1997). For assessment of changes in bone or cartilage the three-dimensional images are better than the standard SE scans, regardless of the number of planes examined. This development has expanded the advantages of MRT over other radiographic examination methods. Systematic advances in MRI procedures have especially improved examination of temporomandibular joints in children (Hall 1994). Furthermore, three-dimensional MRI data can also be used for guiding special milling machines or stereolithography equipment to produce three-dimensional models (Bumann et al. 1992). The diagnostic value of these models is still meager at this time, however.

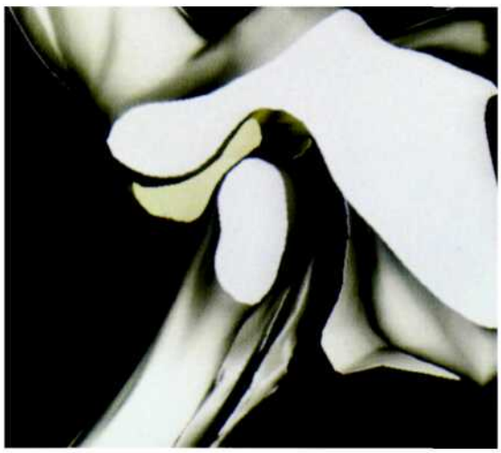


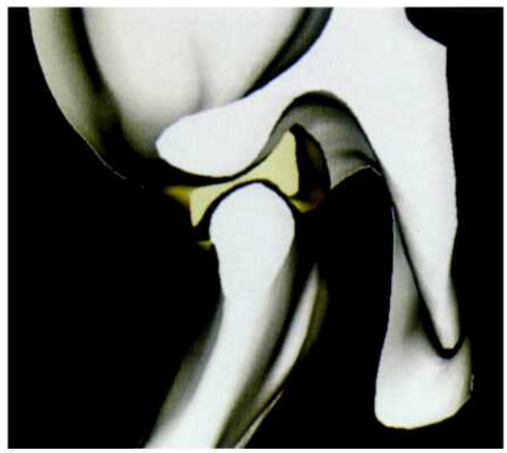


523 Preparation of an MR image
Left: To make a spatial representation of the joint structures, first a conventional T1-weighted image must be made. The slice thickness and the resolution parameters used are dictated by the quality of the tomograms desired and the available measurement time.

Right Three-dimensional images can also be made in the therapeutic condylar position or at maximum jaw opening provided the necessary base data are present.

Collection of C. Price

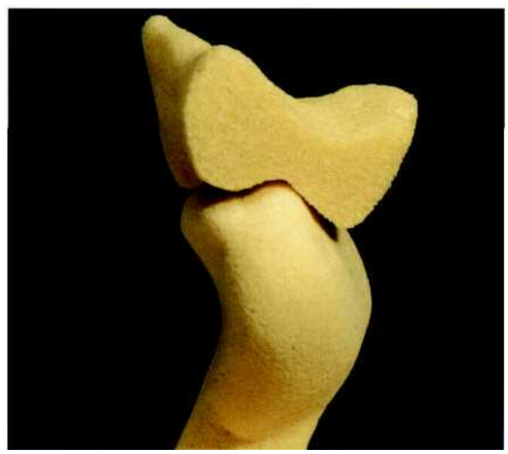




524 Three-dimensional visualization on the monitor
Left: With special software and enough computer capacity the MRI data are converted into a quasi-three-dimensional image.

Right: Disk (yellow) and bone structure (beige) can be colored, rotated, and observed from different sides. It is also possible to superimpose tracings of condylar movements.

Collection of C. *Price*



525 Fabrication of models from MRI data
Left: Enlarged Styrodur model of a disk-condyle complex with the jaws closed. The models are made in a way similar to that described on page 157, except that MRI data are used to guide the milling machine.

Right: Three-dimensional model of the disk-condyle relationship with the jaws open. A dull clicking could be palpated clinically due to the deformed articular surface of the condyle.

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Dynamic MRI

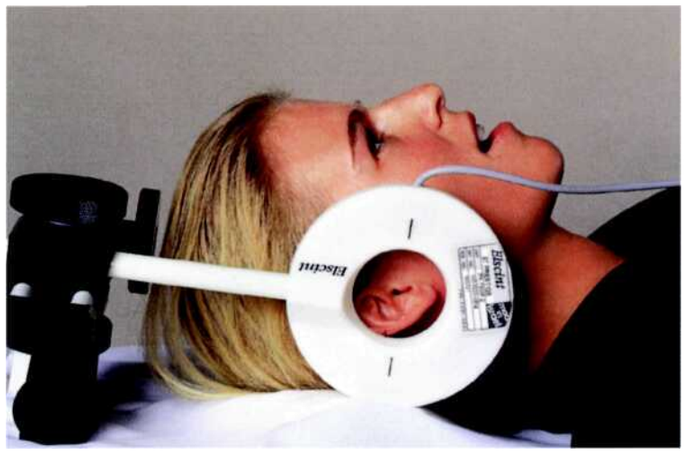
Among the techniques for reproducing movements with MRI, a distinction is made between those that are pseudodynamic (Cine technique) and truly dynamic (Movie technique).

Cine MRI

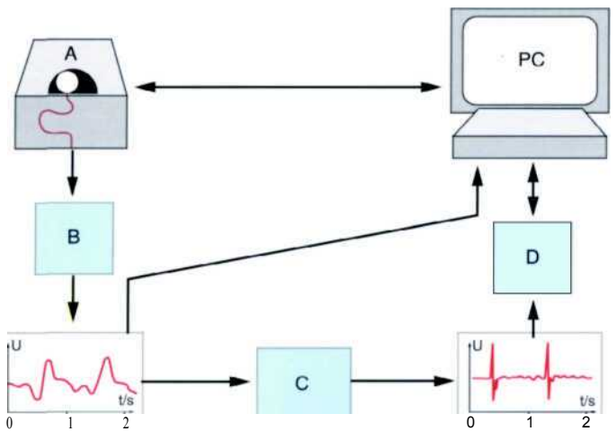
In the Cine technique separate phases of the jaw opening and closing movements are recorded. The individual static exposures are arranged sequentially to create a cinematographic representation of the movement of the temporomandibular joint (Helms et al. 1986, Burnett et al. 1987, Katzberg 1991). The individual phases of movement are recorded at various degrees of jaw opening. The jaws are supported at each position by a special instrument (Burnett et al. 1987, Vogl et al. 1992) or by bite wedges of different thicknesses (Bell et al. 1992).

While it is true that pseudodynamic MR images are visually very impressive because of the view of the joint movements that would otherwise not be possible (Conway et al. 1989, Fulmer and Harms 1989, Kordal? et al. 1993, Yustin et al. 1993, De Mot et al. 1994, Dorsay and Youngberg 1995), they

526 Cine technique
For a pseudodynamic display of temporomandibular joint movements one must make six to 12 static exposures at different degrees of mouth opening. These are then combined for cinematographic visualization. Each jaw position is held steady either by the patient or by means of a wooden spatula, bite block, or special hydraulic mouth prop.

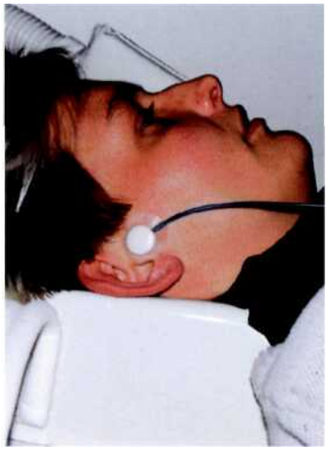


527 Movie technique
Diagram of movement triggering for true dynamic MRT. The continuous opening and closing jaw movements of the patient in MR tomograms (A) are relayed to a breathing monitor (B) by a pressure sensor. From there the signal is relayed either directly or after conversion (C, D) into an ECC signal to the PC of the MRI instrument. There it guides the appropriate scanning sequences by means of special software.



528 Sensor for Movie technique
Clinical arrangement of the pressure sensor and the temporomandibular coil with the patient reclining. The patient must hold the head as still as possible, but this is very awkward from this position because when the jaws are opened while lying down, the head has a tendency to make a reflex backward movement.

Right: Attachment of the pressure sensor over the right temporomandibular joint.



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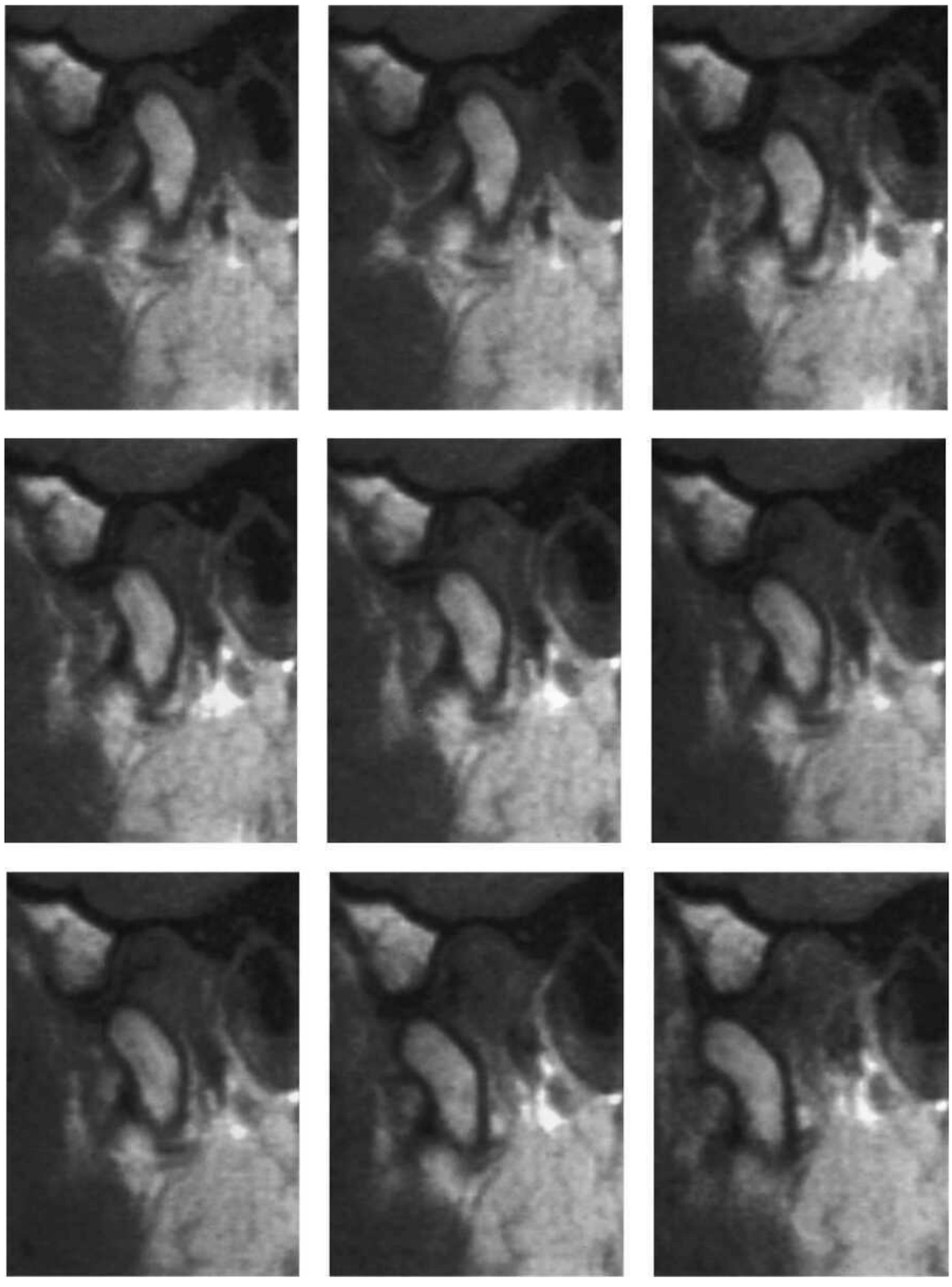
provide no significant new diagnostic information (Bumann et al. 1992, Behr et al. 1996, Ren et al. 1996).

Movie MRI

The Movie MRI technique involves the scanning and completely dynamic reproduction of jaw opening and closing movements. A triggered analysis of the movements is accomplished through either an ECG signal or the inspiration or expiration phases of a breathing monitor. Production of true dynamic images (MR movie) was first described by our team for imaging the temporomandibular joint (Bumann et al. 1996, Schroder et al. 1992). With advances in technology and increased computer capacity, they have experienced increased usage, especially in the study of cardiovascular problems (Wedeen et al. 1995, Iwase et al. 1997) and as a diagnostic tool in internal medicine (Evans et al. 1993). Tl-weighted gradient-echo sequences are best suited for scanning. True dynamic imaging can provide additional information about functional loading of individual parts of the joint such as the joint capsule, the bilaminar zone, and the pars posterior that cannot be gained from static images. In cases with disk adhesion, the extent not only of the adhesion but also of the hypermobility of the lower joint chamber can be determined.



529 Dynamic MRT (CINE technique)
Representation of the jaw opening movement of a left temporomandibular joint in nine phases of movement. Each tomogram is made at a defined jaw opening that is determined by a special apparatus. The quasi-dynamic reproduction of the opening movement can reveal no decisive information concerning loading of the joint capsule or the bilaminar zone, however.
In the upper joint space a normal, unrestricted translating movement of the disk relative to the glenoid fossa is seen. In contrast, there is hypermobility in the lower joint space because of a clear tendency for anterior disk displacement and the associated overstretching of the inferior stratum.

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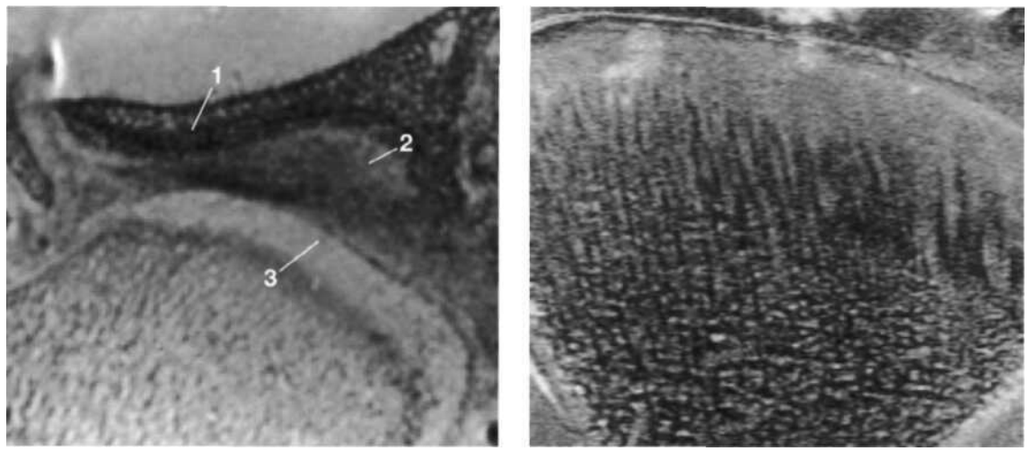
MR Microscopy and MR Spectroscopy

Because of legal restrictions, the maximum strength of magnetic fields presently allowed for examination of humans is 2 tesla. By using stronger magnetic fields (7-14 tesla) and gradients it is possible to produce images with microscopic resolution (approximately 25u) (Koizuka et al. 1997). This is referred to as MR microscopy.

By means of MR microscopy of the temporomandibular joint, individual layers of the articular cartilage can be viewed (Dannhauer et al. 1990, 1992). The contrast of the joint structures can be substantially improved by the application of Mn^{2+} ions (Kusaka et al. 1992). Although this method has already found use in dermatology (el Gammal et al. 1996, Song et al. 1997), it has not yet been implemented for improving examination of joint surfaces because of the limited number of experimental studies.

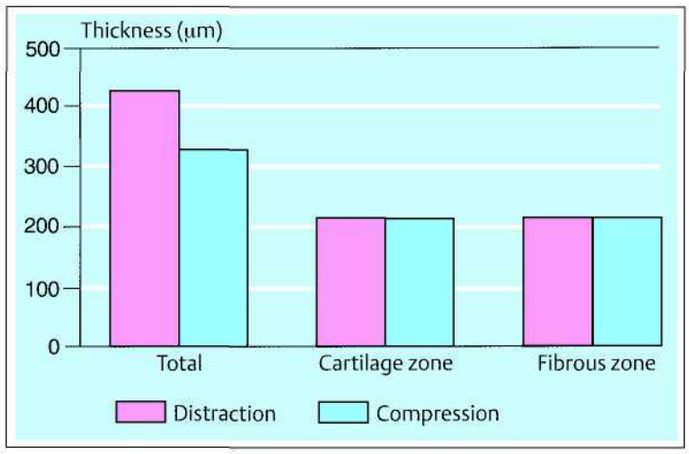
MR spectroscopy is used as a noninvasive method of investigating the metabolism of the muscles of mastication (Lam and Hannam 1992, Chang et al. 1995a, b, Marcel et al. 1995).



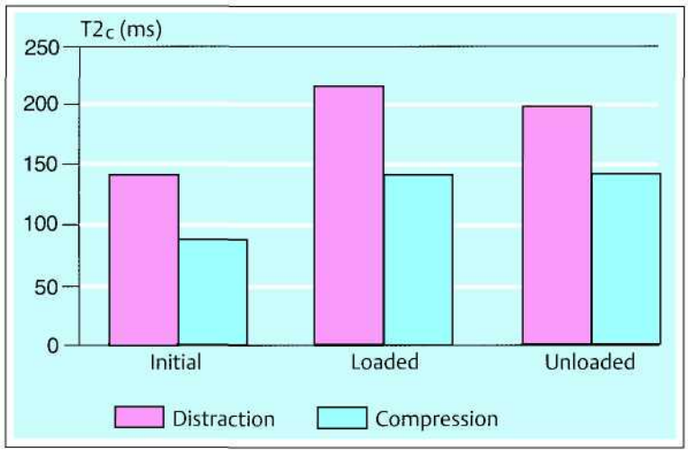
530 MR microscopy
Left: Sagittal view of the right temporomandibular joint of a domesticated pig. The fibrocartilaginous parts of the fossa (1), disk (2), and condyle (3) are clearly demarcated.

Right: In the frontal view, too, the same structures can be clearly identified. Recent developments will make it possible to combine MR microscopy with three-dimensional reconstructions (Smith et al. 1996, Koizuka etal. 1997).

Collection ofK. H. Dannhauer



531 Effect of compression and distraction on the thickness of the functional articular cartilage
Joints under experimentally produced compression experienced a reduction in the thickness of articular cartilage of approximately 25% (Dannhauer 1990). The reduction exclusively affects the fibrous zone and not the cartilaginous zone. Similar findings have been described for joint compressions in connection with midline distraction osteogenesis procedures in the mandible (Harper et al. 1997).



532 Proton shifts during acute compression and distraction of joints
High-resolution MRT is not only useful for producing images, but is also extremely well suited for determining the water content of living tissues (Querleux et al. 1994). More intra-articular free water ($T2_C$) can be demonstrated during the loading of a distracted temporomandibular joint than with joints that have been compressed for some time (Dannhauer 1989)

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Indications for Imaging Procedures as Part of Functional Diagnostics

The conventional panoramic radiograph is well-suited as a screening tool for primary temporomandibular joint diseases (see also p. 270). It has a high sensitivity (0.81) and specifity (1.00) (Larheim et al. 1988). Its usefulness for evaluating the temporal portion of the joint is limited, however (Rohlin et al. 1986). There are no solid indications for the temporomandibular joint program of the panoramic x-ray unit, and the Schuller projection radiograph is considered obsolete as a functional diagnostic aid. Like conventional tomograms they have only a minimal influence on the diagnosis and treatment planning of temporomandibular joint diseases (Nilner and Petersson 1995, Callender and Brooks 1996). Tomograms are indicated only when there are persistent joint problems (such as painful grating during dynamic compression) accompanied by negative or equivocal findings in the panoramic radiograph. CT and three-dimensional reconstructions are indicated in cases of fractures and ankylosis for determining if there is a need for surgery and, if so, for planning the procedure. MRI is the method of choice for determining the disk position and assessing progressive and regressive adaptations.

	Morphology		Position relationships		Adaptation	
	Condyle to fossa	Disk bilaminar zone	Condyle to fossa	Disk bilaminar zone	Condyle to fossa	Disk bilaminar zone
Panoramic radiograph						
Tempo-romandibular joint program						
Schuller projection						
Conventional tomogram						
CT						
MRI • T1-weighted • T2-weighted						
Dynamic MRI						

533 Indications for imaging procedures in functional diagnosis

Green strong indication
Yellow limited indication
Red not indicated

The panoramic radiograph is a good technique for detecting bony changes in the condyle and fossa. Because temporomandibular joint programs and Schuller projections, on the other hand, provide no additional information related to treatment, those boxes are colored yellow.

Sensitivity and specificity of the Schuller projection are likewise acceptable (Larheim et al. 1988). But because of the radiation exposure (71-115 nCy to the hypophysis and 53-65 ^Gy to the temporomandibular joint; 1 [xGy = 0.1 rad) and the lack of additional information, there is no good indication for its use in functional diagnostics.

With conventional tomograms the contours of the condyle and fossa can be accurately evaluated. The "joint spaces," too, can be more precisely measured than in the three exposures previously mentioned.

Because the position of the condyle is not a reliable indication of the position of the disk (Katzberg et al. 1983b, Ronquillo et al. 1988), and because neither the condylar position nor other radiographic findings have any influence on the diagnosis or treatment, the additional radiation exposure various TMJ x-rays (Brooks and Lanzetta 1985) is not justified.

Next to the panoramic radiograph, MRI is the method of choice among diagnostic imaging procedures for the temporomandibular joints. It is especially useful for disk displacements with repositioning without adaptation of the bilaminar zone and for disk displacements without repositioning. Chart modified from Hatcher and Lotzmann 1992.

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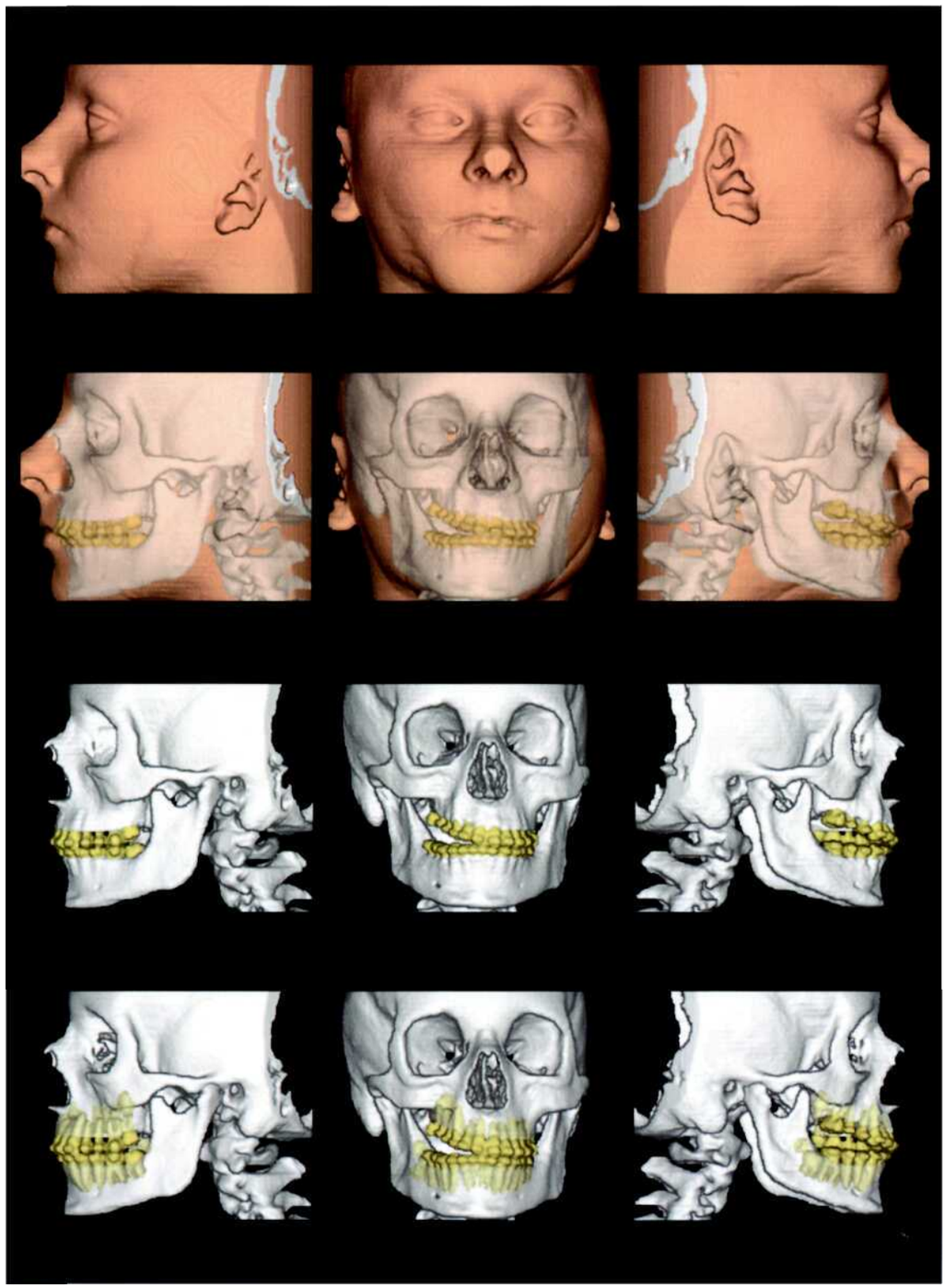
Prospects for the Future of Imaging Procedures

MRI is the imaging procedure of the near future. Three-dimensional images and viewing of true dynamic movements in real time will gain more prominence. One application of this is panoramic MRI of the mandible (Nasel et al. 1998). By employing newer software and liposome-bound contrast agents, the diagnosis of cartilaginous lesions in small joints will be significantly improved (Griinder et al. 1998, Uhl et al. 1998). So-called interactive functional MR scanners permit shorter scan times for MR data and rapid reconstruction in all dimensions of space (Frank et al. 1999, Lee et al. 1998). Today, true dynamic imaging in real time is already a reality for heart examinations (Kerr et al. 1997), but for the temporomandibular joint this technology is still in the experimental stage (Krebs et al. 1995).

Laser scanning of the superficial soft tissues combined with CT of the bone (Arridge et al. 1985, Moss et al. 1991) will surely be carried further by the addition of MRT. This data will then be able to support surgical navigation systems (Wagner et al. 1995, Millesi et al. 1997, Enislidis et al. 1997).



534 Three-dimensional representation of soft tissues, bone, and tooth structures
These images of the hard and soft tissue structures of a patient with a lateral open bite ("open occlusal relationship") on the right side were created from CT data, three-dimenionsal reconstructions, and interactive data processing at a computer work station. Similar images can be produced by data from laser scanning of the soft structures combined with data from a CT scan of the skeletal and dental structures. The different shades of gray of the different structures can be converted to different colors for differentiation, and structures can be subtracted from or added to the image.
In the future, three-dimensional scanners will capture data from the extraoral soft structures and the teeth, while CT will, for the time being, still acquire the data from the bone structure. With technological advances and further development of the software, MRI techniques will come more and more into the forefront. The exposure of patients to radiation that up until now has been unavoidable will thereby be eliminated. In the future, the combination of these data will allow digital tooth setups and digital practice operations on models that can then be repeated clinically under the guidance of surgical navigation systems. This will be of special benefit in the treatment of malformations and syndromes involving the facial skeleton.
Treatment of functional disturbances of the temporomandibular joint will profit relatively little, however, from these advances in imaging procedures because the primary goal of treatment will still remain the elimination of etiolgical factors and restrictions of movement.

Collection of]. Hezel

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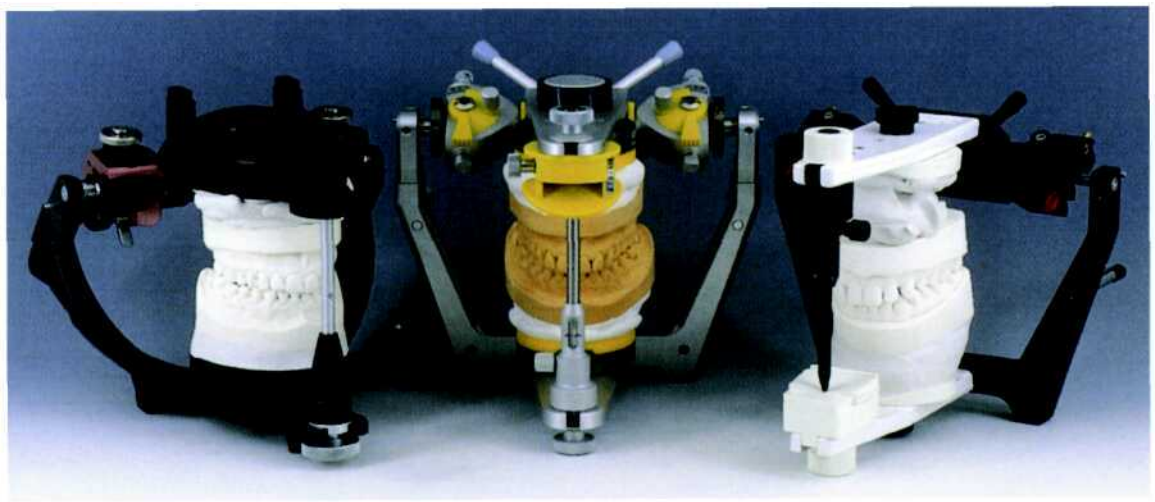
Mounting of Casts and Occlusal Analysis

In the field of dental functional diagnosis, dimensionally accurate casts of the dental arches that have been mounted in an adjustable articulator in the correct relation to the cranium and temporomandibular joints serve to complement the clinical examination (instrumented occlusal analysis I). They are also useful for documentation and, if necessary, for providing legal proof of the patient's current occlusal condition. In some cases correctly mounted casts modified by diagnostic waxup, selective grinding and/or setup, are the primary requirement for preparing and carrying out an occlusal pretreatment as well as for planning the definitive treatment (instrumented occlusal analysis II).



535 Articulator systems
In principle, all articulator systems that have a stable mechanical joint and permit at least semiadjustable settings for the condylar inclination and the Bennett angle are suitable for evaluating the occlusal relationship of casts mounted in centric. In some cases the ability to simulate retrusive movements may be desirable. The articulators shown here are essentially equivalent: KaVo, SAM, Artex (from left to right).

One of the many advantages of an instrumented occlusal analysis is that it allows one to analyze the positional relationships between the teeth and alveolar ridges and to make as many trial alterations as desired under direct vision in the absence of the patient. As a supplement to the gathering of clinical information, it is especially useful in determining whether pain and functional limitations described by the patient could be linked with occlusion-forced guidance and incorrect loading (occlusal loading vectors).

Some of the individual features that can be evaluated are: the shape and intermaxillary relation of dental arches and alveolar ridges; the transverse and sagittal contours of the compensating curve; horizontal and vertical relationships of the anterior teeth; stability of the position of maximum intercuspation; location and inclination of active and inactive abrasion facets; the pattern of occlusal contacts in static and dynamic occlusion; and the path the mandible follows in moving out of the centric, adapted, or treatment condylar position into the maximum intercuspation position. The diagnostic value of instrumented occlusal analysis depends not only on the utilization of precise casts, but also on the quality of the jaw relation records.

If there is any doubt regarding the accuracy of the recorded jaw relation, the occlusal contacts on the casts should accordingly be interpreted with a degree of caution. Premature occlusal contacts are not necessarily the cause of other functional disturbances, but are even more likely to be their result.

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Making of Impressions and Stone Casts

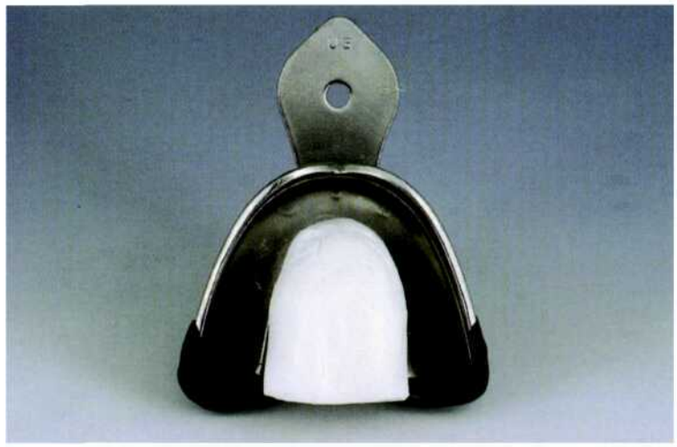
Alginate is the impression material of choice for making casts to record the current situation, to oppose working casts and for occlusal diagnosis, as well as casts for the fabrication of occlusal devices and record bases. When handled correctly during and after making of the impression, alginate permits production of casts with sufficient precision in surface detail and shape. If an impression is be made of teeth that are extremely loose, one should resort to hydrocolloid because of its lower viscosity. The preferred impression tray is one that is rigid and nonperforated with mechanical retention at the rim (Schottl 1978). Alginate and hydrocolloid impressions should be poured with dental stone within half an hour after removal from the mouth. If multiple casts are to be poured in the same impression then a silicone impression material is recommended. This is especially true if there is a heightened need for disinfecting the impression. For high-quality casts it is recommended that only dental stone that has been mechanically mixed under vacuum be used. It should be mentioned that not every brand of alginate or hydrocolloid is compatible with every dental stone.

536 Materials for alginate impressions
Rigid metal trays, thermoplastic impression compound, alcohol burner, silicone putty, and alginate adhesive.

Right: Use of a mechanical mixer (here, by Hauschildt) reduces the inclusion of air bubbles and ensures a homogenous mix of alginate.

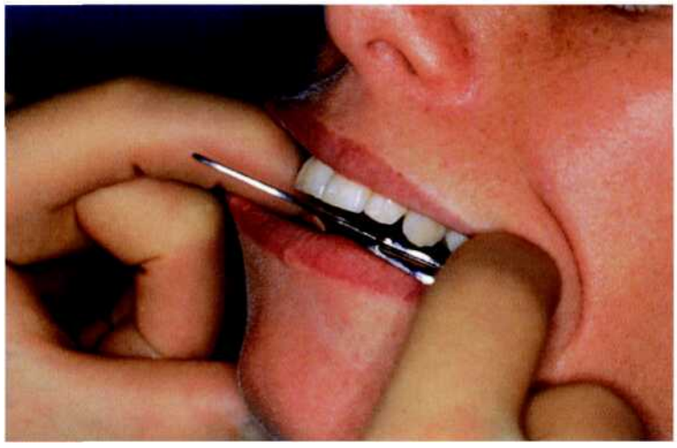
537 Preparation of the impression tray
A palatal stop of silicone putty facilitates placement of the impression tray in the patient's mouth. The post dam is made preferably with impression compound. The mechanical retention of the alginate in the tray should be reinforced by applying an alginate adhesive.

Right: A tray size should be selected so that the distance from the teeth to the inner surface of the tray is about three to four times the depth of the undercut.



538 Alginate impression
The alginate-filled tray is inserted over the anterior teeth first, then over the posteriors. The patient should close the mouth nearly all the way, but without biting on the tray. The tray is held in place until the alginate has set. During this time the patient should relax the muscles and avoid swallowing or making other tongue movements.

Right: To avoid trapping air bubbles in the important occlusal areas, the teeth should be smeared with alginate just before the tray is inserted.



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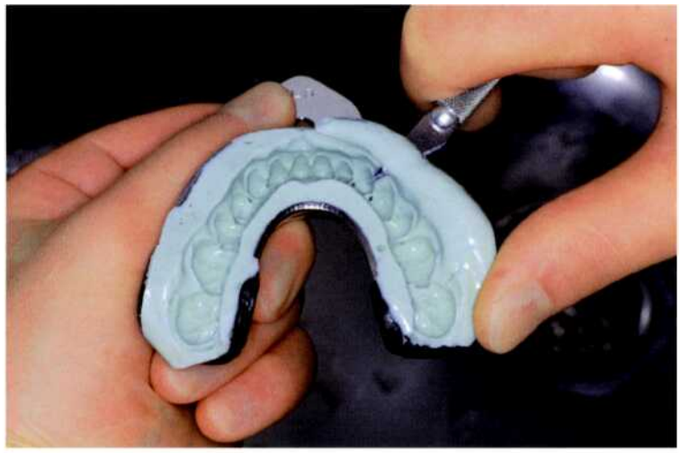
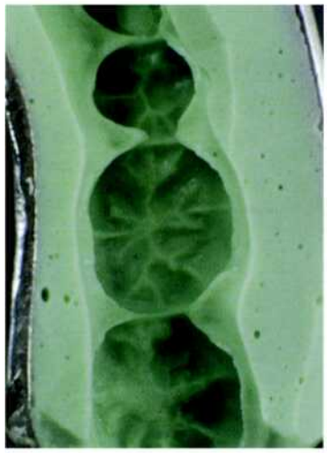
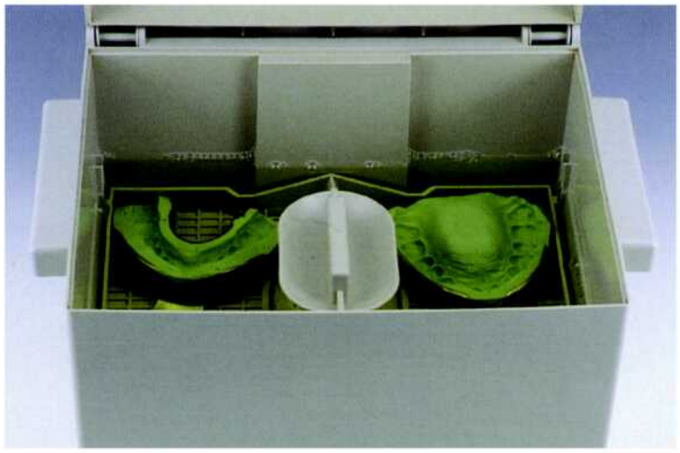


Further treatment of the alginate impression

539 Trimming
After the impression is removed from the mouth, it is carefully examined to make sure the alginate is well bonded to the tray. If the impression has separated from the tray it must be remade.
The impression may be trimmed back to the level of the tray provided further work, such as the construction of an occlusal splint, will not require reproduction of the border areas.





540 Disinfection
The impression is cleansed of any adhering blood and saliva by rinsing under lukewarm water and is then immersed in a disinfectant bath. The prescribed working time for the particular disinfectant being used must be strictly observed. After removal, the impression is once again rinsed under flowing water.

Left: A bubble-free impression is a prerequisite for a cast with accurate detail.

541 Interim storage
Alginate impressions should be stored for about 15 minutes (100% humidity) in a humidifier so that regions deformed by the removal of the impression can rebound (Meiners and Lehmann 1998).

542 Binding of the alginic acid
The surface quality of the stone cast can be improved by sprinkling stone powder over the impression to bind with the remaining alginic acid before the impression is poured.

Left: After it has been in contact with the alginate for a brief time, the stone powder is carefully rinsed away under running water.

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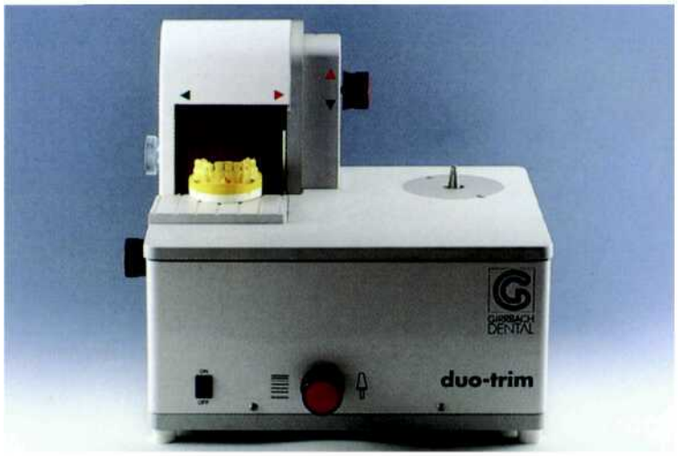
543 Pouring and boxing the impression
After the dental arch has been filled with dental stone, the tray is placed on the base of a Foldox Base Former. The flexible side walls are then wrapped around the tray and the resulting cavity is filled with dental stone.

Right: With the help of a fine brush to avoid bubbles, the impression is filled with vacuum-mixed, hard-setting dental stone.

544 Dry trimming
Once the stone cast has hardened, it should no longer come in contact with water. Therefore the use of a dry trimmer (shown here, the Duotrim by Girrbach) is recommended for touching up the base of the cast.



545 Refining the cast
Under a stereo microscope, small nodules of stone are removed with the tip of an X-Acto knife. Nodules that cover a significant area, especially of the occlusal surface, cannot be removed without compromising the accuracy of the cast and require that a new impression be made.

Right: Binocular head-mount loupes (e.g. by Zeiss) are also recommended for inspecting the critical areas of the occlusal surface.

546 Casts ready for mounting
The maxillary and mandibular casts have been dry-trimmed and their occlusal surfaces prepared for mounting.
For filing, the following information should be written on the casts: patient's name, birthday, or patient number; date of impression; first, second, or third cast; simulation or master cast. After mounting on an articulator, the type and number of the articulator is added.

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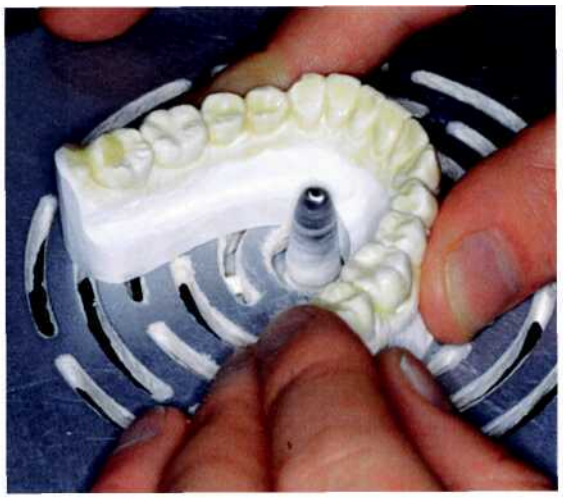
Fabrication of Segmented Casts

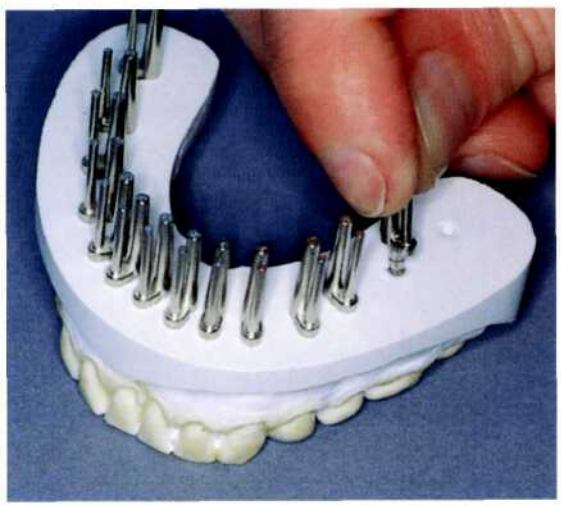
Segmented casts are used primarily to provide removable dies for the fabrication of fixed prostheses. However, they are also useful for making a detailed analysis of a patient's static and dynamic occlusal relationships. For one thing, the removal of an entire quadrant improves the view of the occlusion in the other portions of the arch. For another, by removing only those teeth that carry the current premature occlusal contacts, the effects of making occlusal changes within their space can be anticipated (see p. 236).

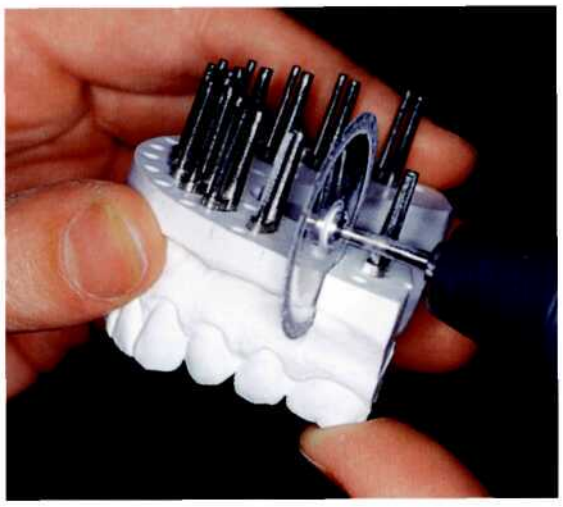
Various procedures have been recommended for producing a segmented cast. In addition to the classic method that uses special die pins as described on this page, another interesting method worthy of mention is the Model-Tray procedure. This uses a base-forming tray that can be disassembled and that has numerous orientation grooves on its inner surface (Model-Tray by Model-Tray GmbH). After the cast has been removed and sawed into sections it can be accurately reassembled in the tray.



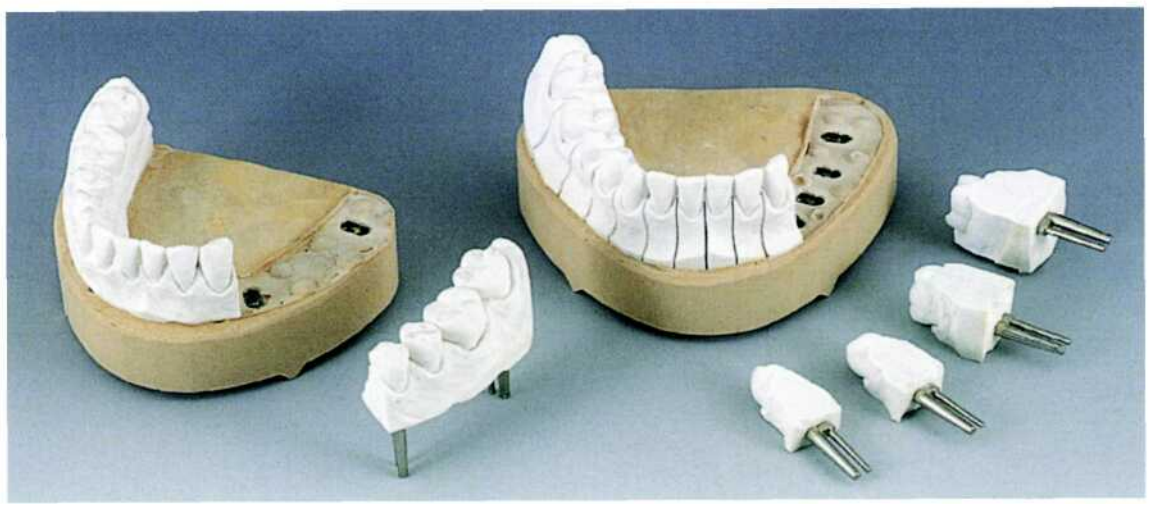
547 Trimming the dental arch and drilling the pin holes
Left: Correct placement of each pin hole is facilitated by projection onto the dental arch of a light ray (red dot) that is coaxial with the intended pin hole.

Right: The basal, facial, and lingual surfaces of the dental arch are trimmed smooth. Any undercuts or rough areas would interfere with removal of the sawed segments after the base is added. Here the teeth have been previously coated with liquid latex to protect them from water and grinding dust.





548 Adding pins and base, and sawing the segments
Left: The dowel heads are coated with quick-setting cyanoacrylate cement and pressed into the pin holes. The sleeves are then slid onto the dowels. Next, orientation grooves are added to the cast, a separating medium is applied, and a base is poured with a type-IV dental stone.
Right After the base has hardened, the cast of the dental arch is removed from it. Saw cuts are made in the cast to just short of the proximal contacts (caution!), then the segments are separated by breaking through the remaining stone.



549 Cast with removable segments for occlusal diagnosis
Although in some cases, segmented casts with one anterior segment and two posterior segments are adequate for a quick occlusal diagnosis *(left),* it is preferable to prepare casts in which each posterior tooth and at least the canines can be removed separately.

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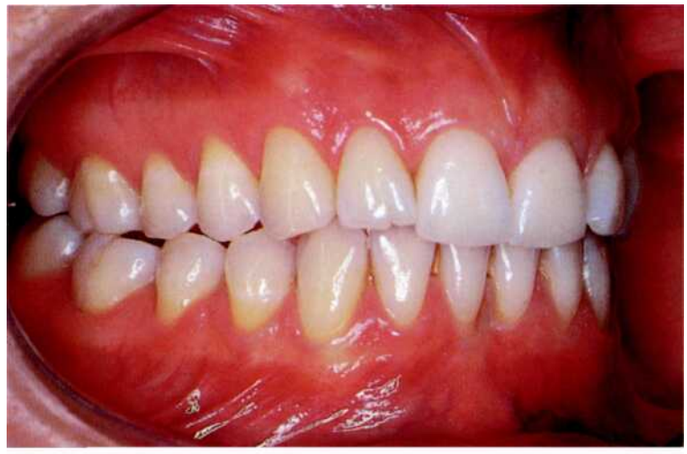
Registration of Centric Relation

The starting and ending position of mandibular movements is usually the maximum intercuspaton position at which the spatial orientation of the mandible to the cranium, and consequently the position of the condyles in their fossae, is determined by the occlusal intermeshing of the upper and lower teeth. Tooth loss or changes in tooth position as well as idiopathic or iatrogenic modifications in the shape of the occluding surfaces can lead to changes in the intermaxillary relation and subsequently to a displacement of the condyles. When this has happened, the clinician in the field of diagnosis and treatment of functional disturbances of the masticatory system faces the decision of whether to keep the jaw relations dictated by the intercuspation or to correct them by reorienting the mandible to the cranium. Every type of diagnostic and therapeutic procedure for mandibular misalignment assumes that the chosen reference position can be precisely and repeatedly recorded and that the joint structures will be physiologically loaded (i.e. in the centric or adapted condylar position). However, the commonly used techniques for registering centric jaw relations often show a clinically unacceptable range of results.

550 Maximum intercuspation position
With the teeth in maximal occlusion the condyles may be displaced in any direction from their neutral centric position. For further diagnosis, the magnitude and direction of the condylar displacement is important. From another aspect, it is worthwhile to clarify whether the condyles are in an adapted or pathological position at this maximal occlusion.



551 Premature contact in centric
The position of the mandibular teeth when the condyles are in their centric or adapted position may disclose a considerable discrepancy in the occlusion. In this case there are centric premature contacts against the lingual surfaces of the maxillary central incisors. Since no definitive "centric" can be determined in the presence of neuromuscular incoordination or protective bracing arising in the muscles or joints, one can only attempt here to register the "momentary centric" or "centric of the day."

552 Centric registration
The centric registration captures the relationship of the mandible to the maxilla at the centric or adapted condylar position. To prevent conditioned neuromuscular deflective movements, the patient must avoid any conscious tooth contact. With natural teeth present, this requires that the recording material offer the least possible obstruction to the occlusion.
When evaluating the significance of occlusal findings, the quality of the jaw relation record must be taken into consideration.

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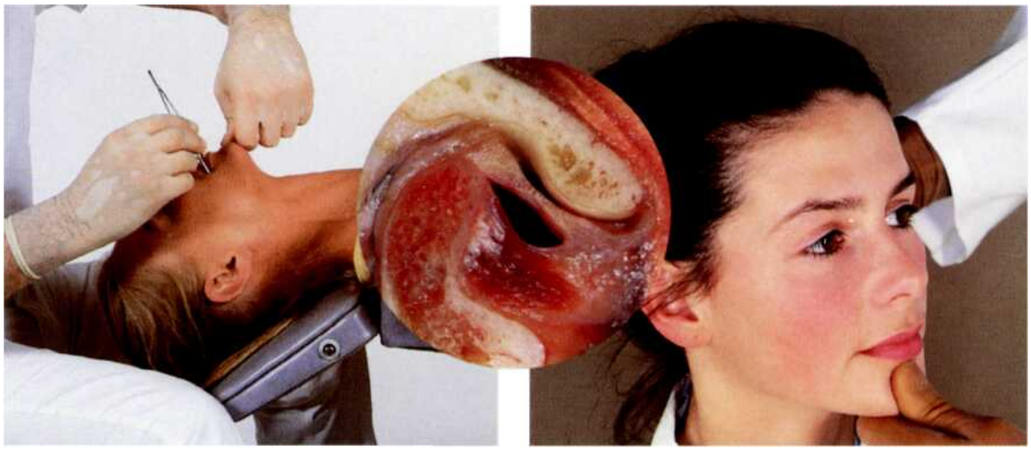
Techniques for Recording the Centric Condylar Position

Many methods have been advocated for registering centric jaw relation using either active, semiactive, or passive manipulation techniques (Lotzmann 1994). In active methods the intermaxillary relation is recorded with no manual or instrumented guidance by the clinician. This actively achieved jaw relation is significantly influenced by muscle tone and by the postural position of the head and body. Therefore it often results in asymmetrical and anterior malpositioning of the condyles, especially in patients with functional disturbances.

Most methods used in practice are *semiactive registration procedures.* While it is true that the patient provides most of the guidance of the mandible into the proximity of the centric region, the movement is either influenced or monitored by intraorally or extraorally mounted devices (e.g., incisal index, intraoral central bearing plates, Myomonitor, paraocclusal axiography).

In passive *techniques* condylar positioning and intermaxil0lary registration are accomplished essentially through manual control by the clinician (e.g., Dawson grasp, three-finger technique).



553 Posterior manipulation
The techniques shown here are obsolete today. Admittedly they provided a condylar position that was reproducible, but not physiological.

Left: Use of the "chin technique" on a reclining patient further intensifies displacement of the mandible. The condyles are forced into a retrusive border position.

Right: Excessive posteriorly directed pressure applied to the chin will always manipulate the condyles posteriorly beyond their physiological position (circular insert).

554 Anterosuperior manipulation
Both techniques shown presume a correct disk-condyle relationship or at least an adapted bilaminar zone.

Left: The object of this manipulation technique from Dawson (1976) is to bring both condyles into their most anterosuperior position against the eminence (circular insert).

Right: The "three-finger technique" also supports the mandible at its angles and helps to avoid posterior and posteroinferior displacement of the condyles.

555 Gentle chin guidance with the head upright
Left: Careful chin guidance serves only to orient the masticatory nerves and musculature. No force is applied to the mandible. With this technique, iatrogenic compression of the joint structures can be avoided, assuming that the muscles are relaxed.

Right: The centric, or at least the adapted condylar position (circular insert) should coincide with a stable occlusion of the posterior teeth.

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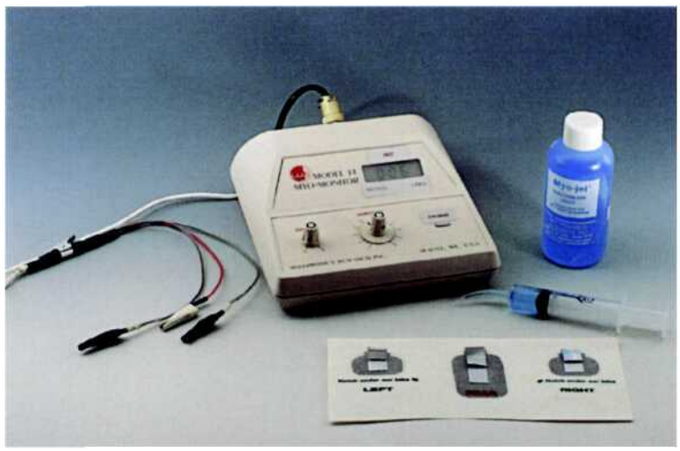
Transcutaneous Nerve Stimulation for Muscle Relaxation—"Myocentric*"

The Myomonitor procedure is counted among the semiactive techniques for the determination of centric jaw relation. The Myomonitor, devised by Jankelson and Swain (1972), produces transcutaneous electrical nerve stimulation (TENS) which induces rhythmic contractions of the stimulated muscles. This in turn relaxes the muscles to achieve a mandibular rest position that is at least temporarily stable and relaxed. Electrical pulses, each lasting half a second and spaced 1.5 seconds apart, are conducted from two active preauricular electrodes to one indifferent electrode placed below the occipital bone.

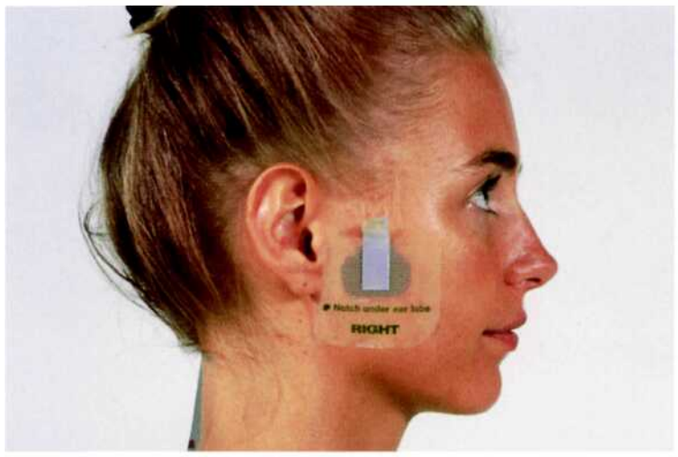
On each side the Myomonitor delivers a maximum electrical potential of 65 V and, depending on the resistance of the skin, a maximum current of 25 mA. Through indirect stimulation of motor branches of the trigeminal and facial nerves, these pulses produce synchronous, mutually balancing muscle contractions. After the Myomonitor has been used for 30-40 minutes the mandibular rest position can become stabilized to a great extent through fatigue and relaxation of the muscles of mastication. This newly defined rest position serves further as the starting point for registra-

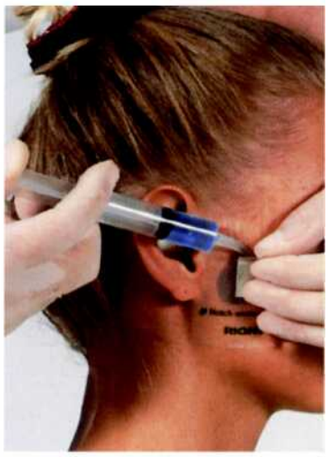
556 The Myomonitor
The Myomonitor, shown here with its set of electrodes, electrode gel, and application syringe, can bring about relaxation of the muscles of expression and mastication through rhythmic transcutaneous electrical stimulation of the facial and masseteric nerves.



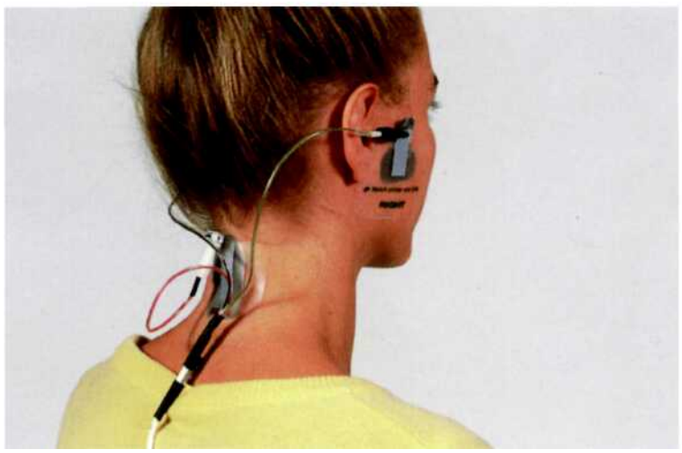
557 Placement of the electrodes
The active electrodes are placed over the preauricular areas on both sides, and the indifferent electrode is centered on the back of the neck just below the hairline.

Right: Contact gel is applied to the skin with a syringe and spread evenly by pressing on the electrode.





558 Cables connecting electrodes to the Myomonitor
The electrodes are connected to the Myomonitor through color-coded cables (green = right; black = left).



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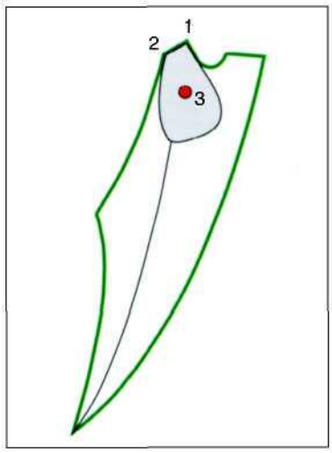
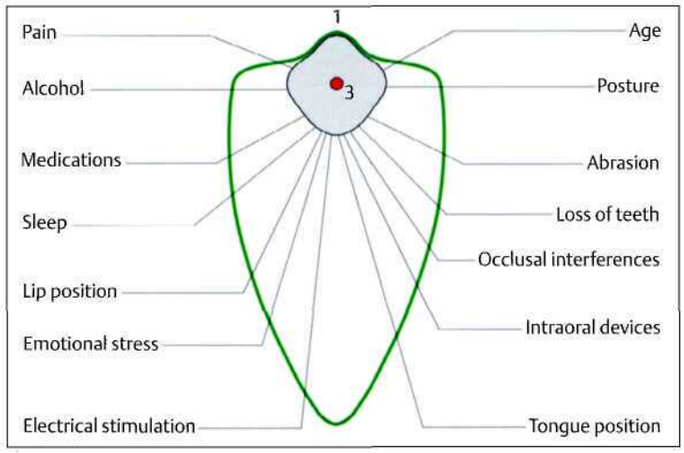
tion of the intermaxillary position referred to as "myocentric." This assumes that with the torso upright and the head held straight, a closing movement of 2-3 mm (the average interocclusal distance) beyond the rest position will place the mandible in the neuromuscularly determined "true" centric position relative to the cranium (Jankelson and Radke 1978a and b, Schöttl 1991). In the majority of cases registered in this way, including patients with successful pretreatment, the condyles will actually lie about 0.6 mm anterior and superior to the centric condylar position (Lotzmann 1994). Following Myomonitor application, patients will frequently notice distinct premature contacts on the lingual surfaces of the maxillary incisors. If the definitive reconstruction is made in myocentric, the space for retrusive movement will be artificially enlarged by the amount of the anterior condylar displacement. The farther the retrusive path extends from the position of maximal intercuspation, the more difficult it is to create an interference-free occlusion by subtractive equilibration or prosthetic reconstruction (Lotzmann 1999). The Myomonitor technique is useful primarily in patients with stubborn muscle tension—especially where there is hypertonicity of the retractors—for registering a preliminary jaw relation to serve as a starting point during the occlusal pretreatment phase.

559 Regulation of the impulse intensity
The amplitude of the electrical impulse is adjusted for each individual patient with the head and upper body in the upright position and the teeth out of occlusion. A uniform, rhythmic contraction of the elevator muscles should be visible.





560 Range of possible mandibular rest positions (gray areas)
Posselt diagram in the frontal plane. The rest position depends on a number of factors. Here the "myocentric" lies on the path of closure of the mandible approximately 3 mm superior to the rest position as determined through use of the Myomonitor.

Left: Sagittal view.

1 Position of maximum intercuspation
2 Retrusive contact position
3 Neutral rest position

561 Interocclusal registration of the myocentric position
The Myomonitor serves here simply to introduce a relaxed and reproducible rest position from which the patient actively but gently closes into the registration material (here, Beauty-Pink-Wax refined with Aluwax).
Apart from this indirect procedure, a direct "myocentric" record can also be made by using the Myomonitor to "pulse" the teeth into a slow-setting registration material (e.g. Myoprint).

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Interocclusal Registration Materials

The classic registration material is hard baseplate wax (e.g. Beauty Pink Wax from Moyco) that is warmed and adapted to the upper teeth and is then corrected on its occlusal surface with Aluwax or a bite registration paste (e.g. Superbite from Bosworth). The slight deformation encountered with wax records can be avoided by using thin metal plates (by Panadent) or bases made of light-curing resin (e.g. Paladisc LC from Kulzer). A more pleasant alternative to the classic registration materials is the special quick-setting, hard registration silicones (e.g. Regisil Pb from Dentsply Caulk, Futar D from Kettenbach). These are available in cartridge systems for convenient mixing and application to the teeth. The resulting silicone records can precisely reproduce the interocclusal relationships. However, because of their residual elasticity they can lead to inaccurate cast mountings. Registration plasters (e.g. Centidur by Girrbach) are also very accurate and easy to use, although they cannot produce thin layers well. If a plaster record cannot be seated on the cast precisely and without rocking, the dimensional accuracy of the cast should be questioned.

562 Wax occlusion record
A "classic" occlusion record of Beauty-Pink-Wax corrected with Aluwax against the lower teeth.

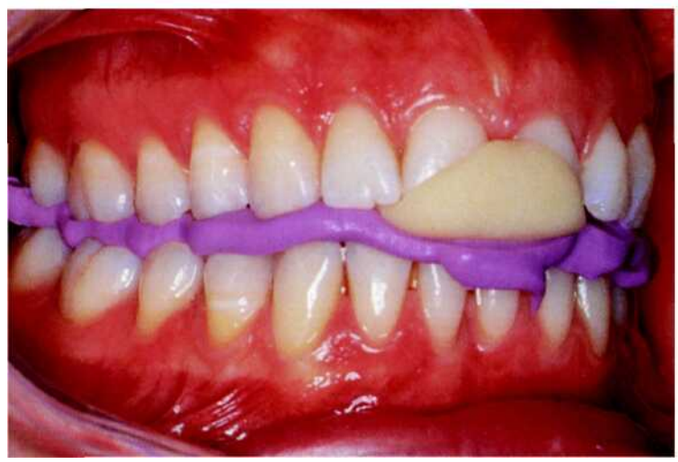
Right: The wax record base is reinforced with an additional layer of wax on both the superior and inferior surfaces of the palatal area. An anterior buildup of wax provides for disclusion of the posterior teeth. Refinement is accomplished by adding Aluwax to the premolar and molar areas to form occlusal stops.

563 Synthetic resin occlusion record
Record bases made of light-curing resin offer the advantage of dimensional stability. They can readily be trimmed back to minimize interference with the occlusion if necessary.

Right: A resin record base on the maxillary cast after occlusal refinement. The anterior bite plane parallel with the occlusal plane helped to avoid posterior tooth contact with the record base.

564 Silicone occlusion record
Whenever silicone or plaster is to be used to register the centric jaw relation, an anterior bite index of cold-curing resin should first be formed to prevent occlusion of the posterior teeth.

Right: The silicone record is judiciously trimmed back with a scalpel and placed to fit precisely on the mandibular cast.
One advantage of this registration technique is that there is virtually no impingement upon the tongue space.



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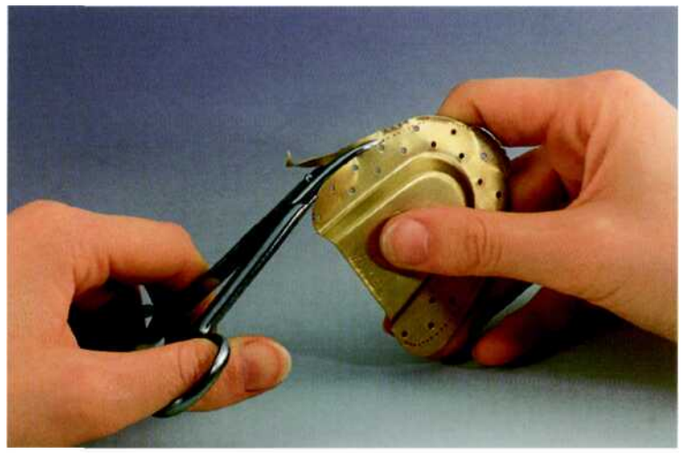
Centric Registration for Intact Dentitions

Patients with all their teeth, or at least with upper and lower teeth occluding in all quadrants, offer a stable foundation for the occlusal registration provided there is no abnormal tooth mobility. This is advantageous for precise transference of the intraoral relationships to the casts. Basically, because all antagonistic tooth contacts must be avoided as the occlusal registration is being made, an excessive vertical dimension will result unless all the teeth have been prepared for crowns, or the vertical dimension must be increased to restore an abraded dentition. The occlusion should be opened as little as possible consistent with the properties of the registration material.

Prior to making the interocclusal record, the masticatory muscles should be deprogrammed by placing cotton rolls in the premolar regions or by some other method. The actual registration is accomplished in two steps:

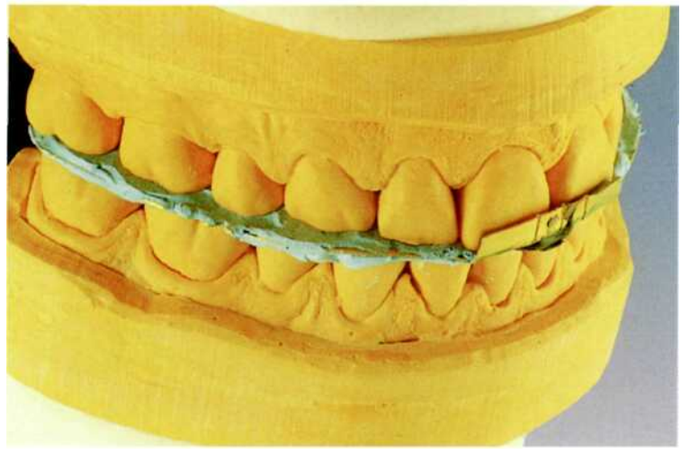
1. Construction of a horizontal bite plane to oppose the lower incisors.
2. Occlusal registration in the posterior region.

Multiple interocclusal records used with the split cast method (see p. 230) can provide information on the neuromuscular stability of the recorded position.



565 Trimming of the record base
In this example, a prefabricated metal plate (by Panadent) is used in making the registration. After the patient has closed the teeth firmly on the plate, it is trimmed back to the width of the maxillary dental arch. Sharp angles are rounded over with a carborundum stone.

566 Interocclusal correction of the record base
The metal base is loaded with a registration paste capable of reproducing fine details (here: Super Bite) and placed against the upper teeth. Adhesion of this registration paste to the metal base can be increased by first coating the metal with a silicone adhesive.
Next an anterior bite index is formed with green stick compound (by Kerr). Finally the occlusion of the mandibular posterior teeth is registered with more fine-detail bite-registration paste.



567 Testing the fit of the occlusal record on the casts
To be able to critically examine the occlusal record for exactness of fit while the patient is still present, the casts should already be on hand when the jaw relation record is made. The sides of the tooth imprints are trimmed back with a scalpel under magnifying loupes. The casts must seat into the record with no gaps.

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Occlusal Splints used as Record Bases

During the course of occlusal pretreatment or, at the latest, immediately after its successful conclusion, it may be necessary to mount upper and lower casts in the current jaw relation achieved with the occlusal splint. This serves the following purposes:

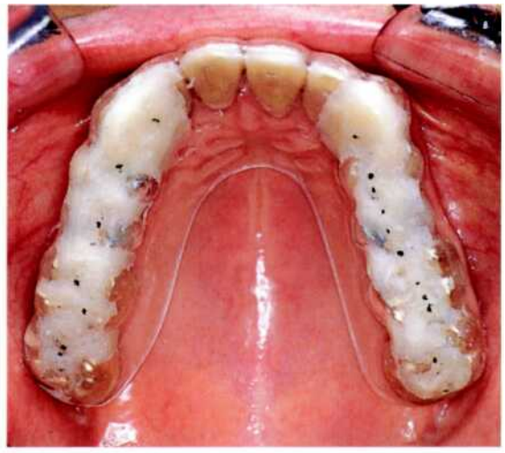
- Occlusal adjustment of the occlusal splint in the articulator
- Testing of the therapeutic mandibular position as registered on the patient by means of the trial mounting base method. (When using the mandibular position indicator or similar registration system, however, there is no new mounting of the mandibular cast.)
- Occlusal diagnosis for planning the measures to be used for the definitive correction of the occlusion.
- Transfer of the stable, comfortable splint intercuspation position arrived at during splint therapy to the definitive restorations.

When the occlusal splint is to be used to carry the occlusal record, there are two different ways of proceeding:

- If the splint is to be remounted for occlusal adjustment, the posterior occlusal regions of the splint are ground back, an anterior bite plane is built up to disocclude the

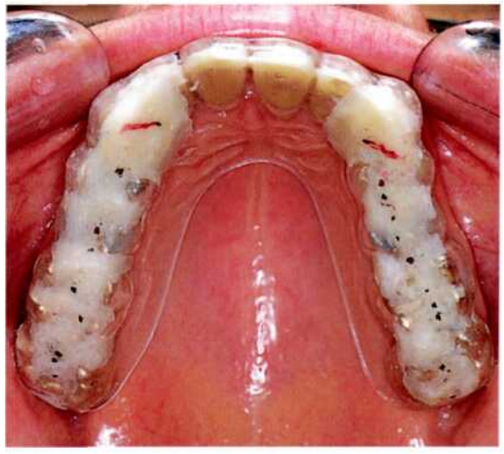
568 Occlusal pretreatment
Left The pretreatment on this patient has been completed with the help of a canine-guided equilibration splint. The patient is free of her previous complaints, and maximal intercuspation with the splint has been stable for 4 weeks.

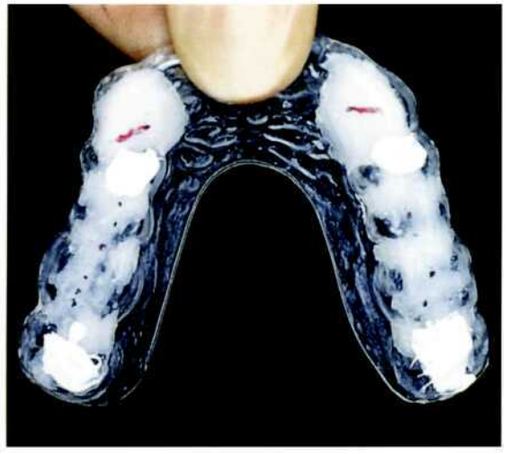
Right: The occlusal contacts have been marked on the splint with black articulating film.



569 Application of registration paste
Left: Testing the eccentric occlusion. The excursive paths marked with red articulating film extend equally. No excursive interferences can be detected in the posterior regions.

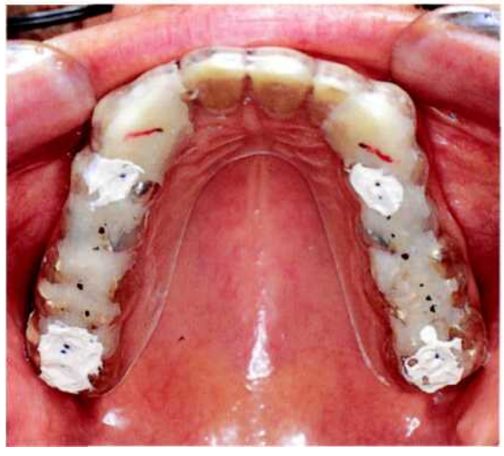
Right: A fine-detail registration paste is applied to the splint only over the first premolars and distal-most molars.





570 Registration of the maximum intercuspation position on the splint
Left: With the head in the upright position, the patient closed gently against the splint. After the registration paste has hardened, the previously marked centric contacts should always be visible at the depths of the occlusal imprints.

Right: In preparation for mounting the mandibular cast, the "splint registration" is seated on a duplicate maxillary cast made before the splint was constructed.



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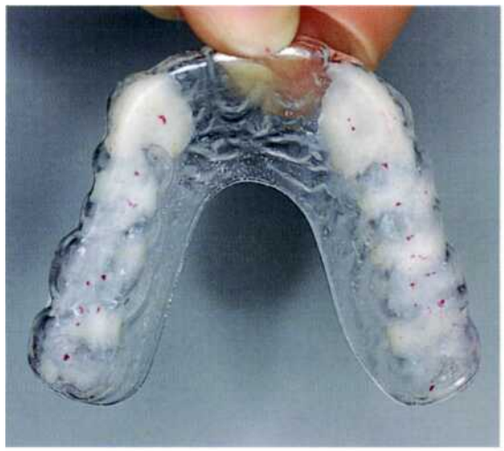
posterior teeth, then fine adjustments are made in the posterior region.

- If the intercuspation with the splint is to be transferred unchanged to the articulator, registration paste is applied in the first premolar and terminal molar regions. Then the patient, with the head and body held upright, closes lightly into the habitual splint occlusion.

In regard to mounting casts for planning the final treatment, it is recommended that the working cast be duplicated before the occlusal splint is constructed. As a rule, the splint can be reseated accurately only on the working cast or its duplicate.

The tried and proven splint intercuspation position must be transferred precisely to the articulator for the definitive restoration. This is especially true for those patients who responded with a clear increase or decrease of symptoms during the course of occlusal pretreatment. The proven splint occlusion can be captured by using an accurate registration- paste immediately before beginning the tooth preparations. Then as the teeth are prepared, the splint is relined in successive steps, with care being taken to preserve the jaw relation established during splint therapy. In this way the splint is transformed into the definitive centric registration record.

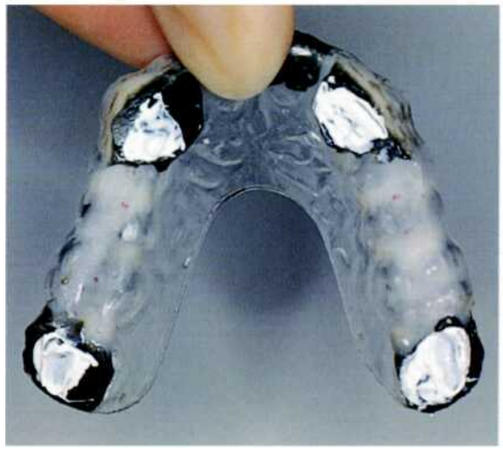


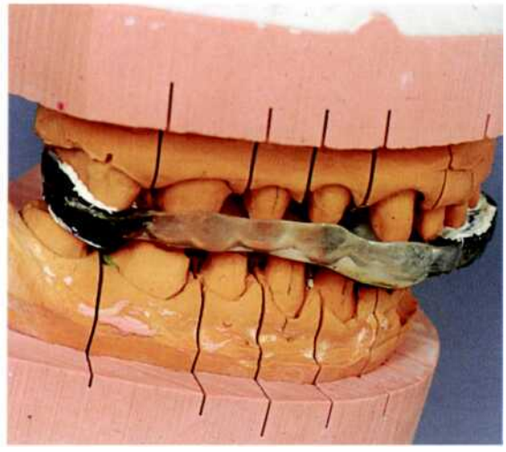
571 Pattern of occlusal contacts
Left: The pattern of occlusal contacts in maximum occlusion as seen on the splint at the conclusion of splint therapy.

Right: Following removal of the old anterior crowns and additional tooth preparation, the splint is readapted to the incisor preparations, here with impression compound and Temp Bond cement.

572 Adapting the splint base to the crown preparations
Left: After removal of the crowns from the distal-most molars, the splint is further adapted on both sides. The original position of the splint relative to the maxilla remains unaltered throughout.

Right: Preliminary preparation of the mandibular incisors and canines.





573 Successive adaptation of the splint occlusion
Left: As soon as the lower canines are prepared for crowns and the distal-most lower crowns are removed, the contact of the occlusal device with these preparations is re-established step by step. This preserves the jaw relation established with the treatment splint.

Right: Mounting of the working casts, here for fabrication of long-term provisional crowns, completes transfer of the stable splint intercuspation position from the patient to the articulator.

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Centric Registration for Posteriorly Shortened Dental Arches

The shape of a centric relation record for a posteriorly shortened dental arch depends, among other things, upon the distribution and mobility of the remaining teeth. As a rule, record bases are used that are supported by soft tissue or, if the dental status permits, by a combination of soft tissue and tooth structure. They can be augmented by a central bearing pin if necessary. These hard resin record bases can be made on a cast that is a duplicate of the one to be mounted and must fit the casts accurately. Under no circumstances should the record base be relined in the mouth or it will no longer fit the master cast.

The bases are built up with rims of hard wax or resin in the areas of missing teeth. If the vertical dimension is to be increased, the remaining teeth are also covered. The occlusal surfaces of the rims are adjusted using occlusal ribbon or tape and then refined with Aluwax or registration paste. It is essential that there be no occlusal contact against the hard rims. An alternate method for free-end situations in the mandible is to add to the upper record base an elongated rim that will contact the opposing alveolar ridge.

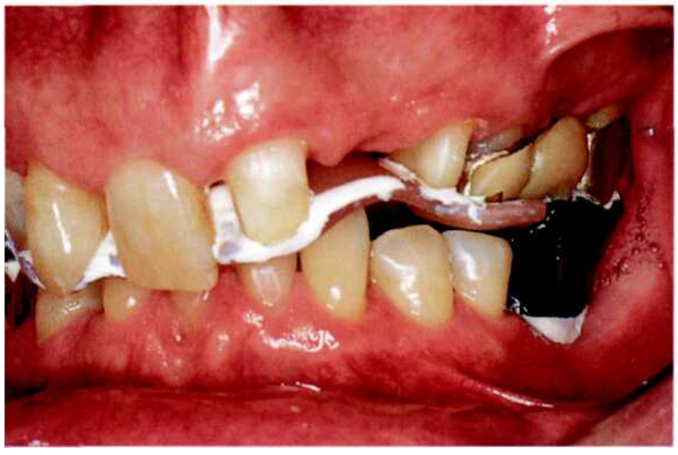
574 Try-in of the preadapted record base
The fit of a record base constructed previously of light-cured resin on a cast of the upperteeth is checked in the mouth. The base has an anterior bite plane to meet the lower incisors and ensure a slight disclusion of the posterior teeth.

575 Addition to the base over the opposing edentulous ridge
The record base is built up with impression compound over the edentulous region until an imprint of the alveolar ridge is made in the warmed compound as the jaws are closed.

Right: Occlusal view of the record base. The impression of the alveolar ridge is trimmed back so that it does not quite touch the ridge mucosa. The only occlusal contact is now on the anterior bite plane.

576 Corrective lining of the record base
Whether or not the record base should be lined with registration paste against the maxillary teeth depends upon the quality of the original fit.

Right: Buccal view of the "free-end saddle" completed with a high-definition registration paste. The impression of the crest of the ridge is formed without pressure.



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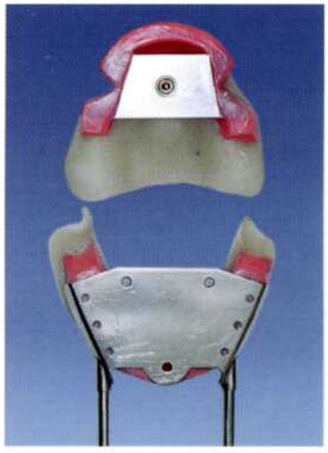
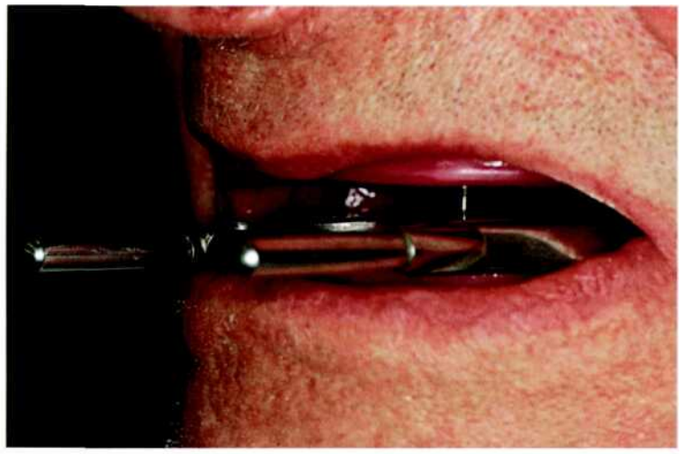
Jaw Relation Determination for Edentulous Patients

With the loss of the last remaining pair of opposing teeth, the orientation of the mandible to the cranium as determined by the patient's occlusion is lost. In determining the correct jaw relation for an edentulous patient one is faced with the challenge of defining anew a physiological mandibular position not only in the horizontal plane but also in the vertical dimension. Determination of the edentulous jaw relation is best accomplished in two steps at two different appointments:

- *Relation determination I:* Establishment of a functionally and esthetically acceptable vertical dimension.
- *Relation determination II:* While preserving the vertical relation established in the first step, the second step involves the actual recording of the centric, adapted, or therapeutic mandibular position in the horizontal plane. Besides the manipulated jaw closure, the intraoral central bearing pin method has proven valuable, especially when there are unfavorable alveolar ridge conditions. If the bearing pin is correctly placed, the record bases will remain essentially stable on the ridges because of the pressure at the center of support. The only disadvantage is restriction of the tongue space.



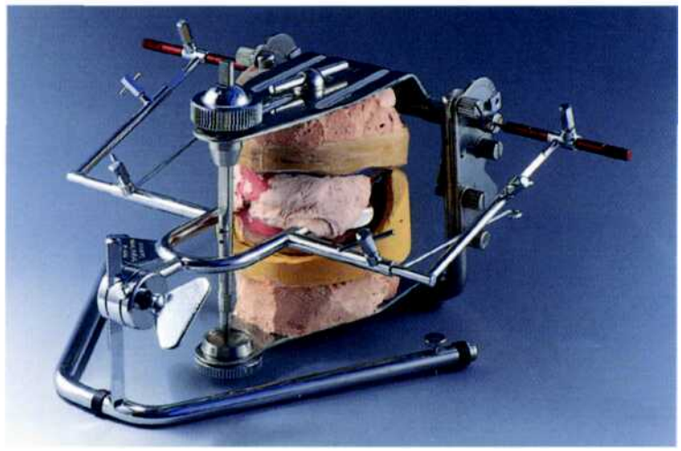


577 Intraoral central bearing system by Gerber (1971)
The mandibular record plate lies in the occlusal plane. The bearing pin is placed at the intersection of the midsagittal plane and a line connecting the two lower molar-premolar regions.

Left: Maxillary and mandibular record bases fitted with an intraoral central bearing system (here: Gerber Set No. 106). The special box-shaped plate on the lower arch allows the Cerber-Face-Bow to be attached later for tracing the condylar paths in the sagittal plane.

578 Arrowhead tracing
The registration plate could also be placed in the maxillary arch if necessary. Its central area is colored with a stick of blue wax. The "arrowhead" (Gothic arch) outline is formed by protrusive and laterotrusive movements of the lower jaw. In addition, the "adduction field" of the mandible is marked by using red articulating tape.

Left: The plexiglass cam is locked in place with its hole over the previously established "centric" bearing pin position.



579 Mounting the casts
The two record bases were keyed together in the mouth at the unforced jaw relation assumed by the patient. Then the casts were mounted in an articulator (shown here: Condylator) by using a face-bow oriented to the arbitrary axis.

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Mounting the Casts in the Correct Relationship to the Cranium and Temporomandibular Joints

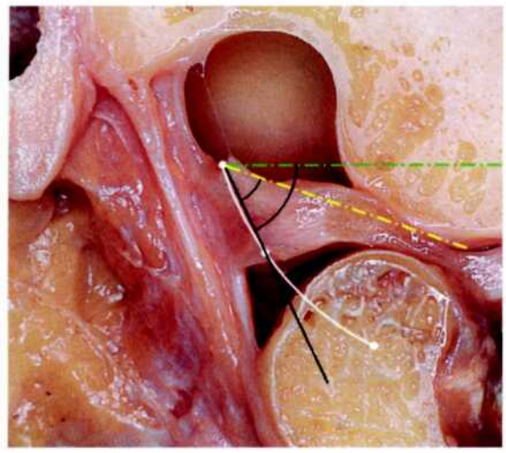
Mounting the casts to simulate the relationship of the jaws to the cranium and temporomandibular joints requires that:

- the dental arches and alveolar ridges are correctly oriented to a physiological or therapeutic condylar position at the established vertical dimension, and
- the casts are mounted to a horizontal reference plane determined on the patient.

With correct cast mounting, the individual orientation of the condylar paths to the occlusal guiding surfaces and to the occlusal plane is essentially preserved. This is a geometric necessity for a close simulation of mandibular movements in the articulator. Commonly used horizontal reference planes are Camper's plane, spina-porion, axis-orbital, and the Frankfort horizontal plane. Camper's plane (tragus to anterior nasal spine) and the spina-porion plane (porion to the anterior nasal spine) run nearly parallel to the occlusal plane and are favored in complete denture prosthetics. In the Frankfurt horizontal plane the reference points are porion and orbitale whereas in the axis-orbital plane they are the hinge axis points and orbitale.

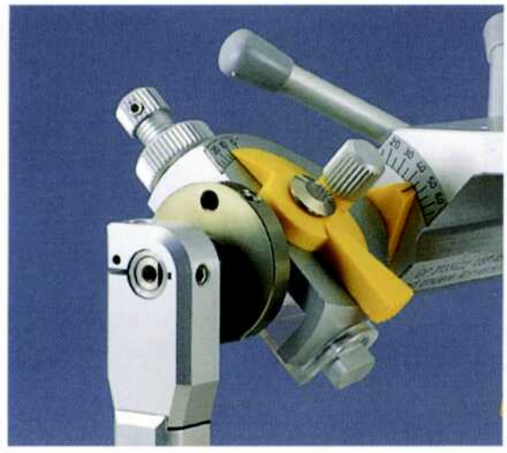
580 Axis-orbital and spina-porion planes
Left The axis-orbital plane (green), spina-porion plane (yellow), and occlusal plane (red) are shown projected onto a lateral view of the face.

Right: Sagittal section of a human temporomandibular joint in protrusive position. The two broken lines run parallel with the spina-porion and axis-orbital planes and intersect at the starting point of the condylar path (white). The angle of the condylar path is necessarily different for the two reference planes.



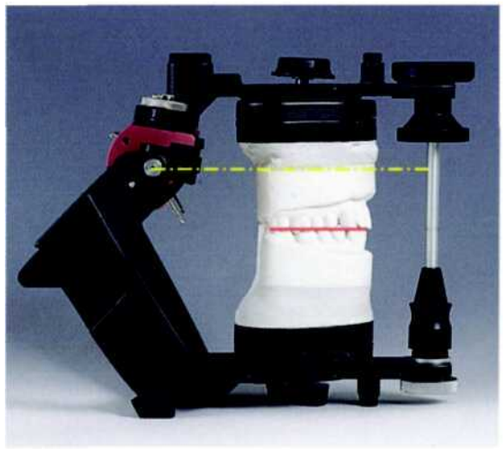
581 Mounting the casts to the axis-orbital plane
Left Establishment of a horizontal reference plane (here: axis-orbital plane; green) is necessary for evaluating and, if indicated, realigning the occlusal plane (red) as well as for setting the condylar and anterior guidance to individual or average inclinations.

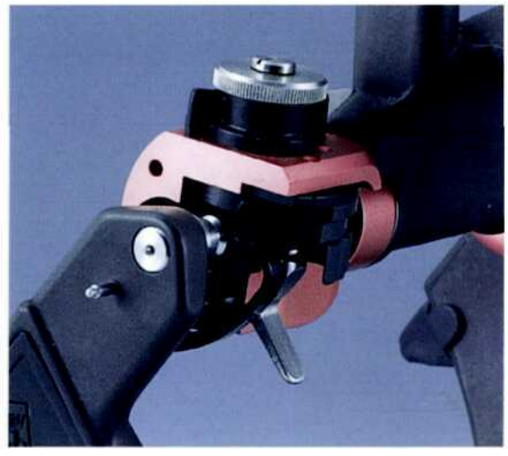
Right Even average value settings are relative to a defined reference plane (e.g. from the axis-orbital plane: 45° condylar path inclination, 10° Bennett angle, 52° anterior guidance angle).



582 Mounting casts to the spina-porion plane
Left Casts mounted relative to the spina-porion plane (yellow). Because the reference points are the hinge axis points and the anterior nasal spine, one can also refer to this more accurately as the axis-spina plane (yellow).

Right: The inclination of the same condylar path will be about 15° flatter when the spina-porion plane is used as the reference plane for mounting the casts than when the axis-orbital plane is used.





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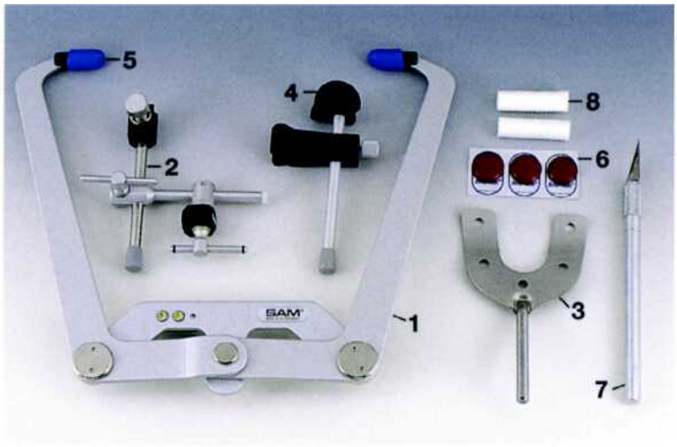
Attaching the Anatomical Transfer Bow

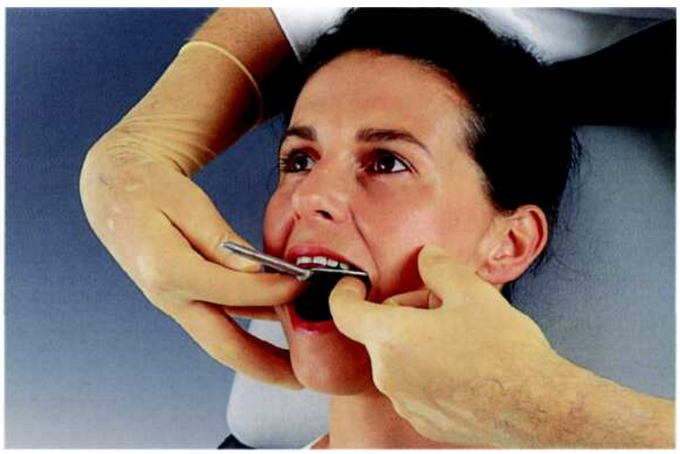
The only reason it is necessary to accurately determine the transverse axis of mandibular rotation is that occlusal errors can appear in the articulator if the casts are not mounted in the correct relationship to the cranium and joints.

An *arbitrary axis determination* based upon average measurements avoids the time-consuming procedure of locating the patient's hinge axis and is adequate for occlusal analysis. For patients with neuromuscular incoordination of the jaw muscles, the dentist must resort to an arbitrary axis position in any case, because translation-free opening and closing movements are often impossible, even with manipulation. As an alternative to using palpation of the lateral poles of the condyles or measurements from landmarks to find the axis points, the so-called "quick transfer bow" has found widespread use in dental practice. It requires no direct measurement or marking of the arbitrary axis points. All quick transfer bows are constructed so that earpieces on their lateral arms fit into the external auditory canals. The horizontal reference plane is defined by a rest at the bridge of the nose, and the arbitrary axis points are automatically determined.

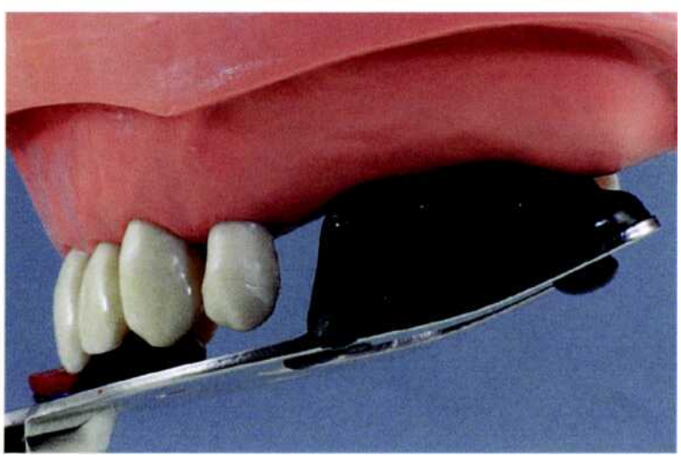


583 Armamentarium
1 Axioquick transfer bow
2 Transfer fork holder, here Type I
3 Transfer fork ("bite fork")
4 Glabella rest
5 Ear pieces with sanitary caps
6 Bite tabs
7 X-Acto knife
8 Cotton rolls

Left: Three bite-tabs are stuck onto the upper surface of the clean, dry transfer fork in the anterior and posterior regions. A firm silicone putty can also be used to customize the transfer fork.



584 Adapting the transfer fork to the upper teeth
The impression compound tabs are softened uniformly in warm water (40° C, 105° F) for 1 minute. Then the transfer fork is seated against the upper dental arch with uniform pressure but without allowing the teeth to penetrate completely through the compound. The handle of the transfer fork is oriented in the midsagittal plane.
Left After the impression compound has cooled, it is trimmed flat with the X-Acto knife, leaving only the imprints of the cusp tips. It is corrected with registration paste only if necessary.



585 Refinement of the transfer fork for posteriorly shortened dental arches
If the number and distribution of the remaining maxillary teeth do not provide stable support, the transfer fork can be built up with impression compound (e.g. Kerr Compound) or a firm silicone until it barely touches the alveolar ridge mucosa.

Left: The impression of the alveolar ridge must always be trimmed back and refined with a registration paste to avoid compressing the soft tissue.

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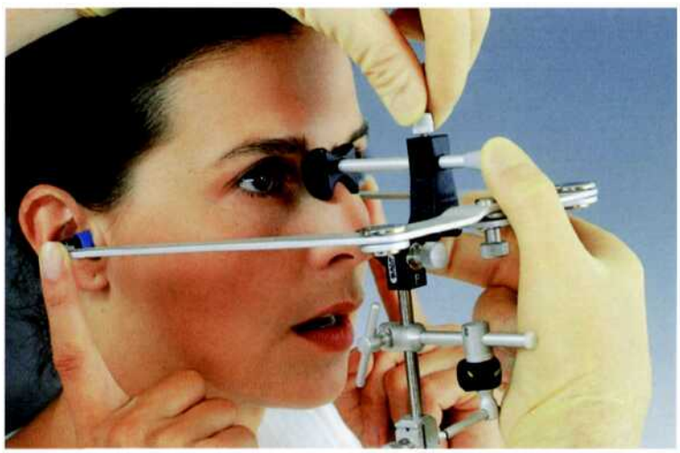
586 Applying the transfer bow
The glabella rest is attached at the center of the bow and slid away from the patient as far as it will go. All the screws remain loose until the transfer fork holder is connected to the bow. The patient holds the side arms of the transfer bow with thumbs and index fingers and, with the mouth open, carefully guides the ear pieces into the auditory canals as she closes the spread arms of the bow.

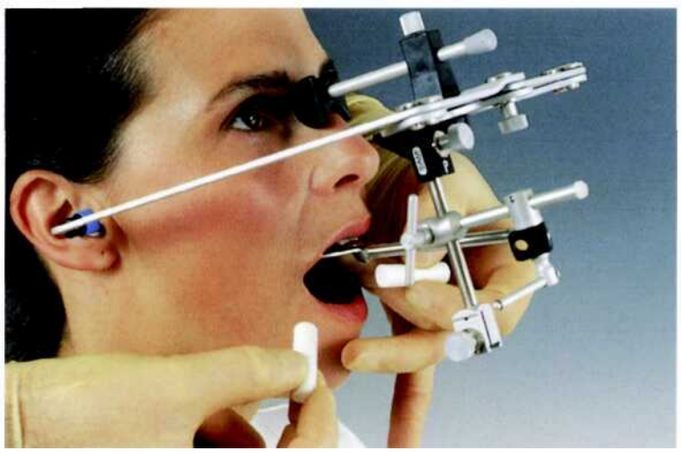
Right: Placement of the ear piece with its sanitary cap.

587 Posterior fixation
While the patient continues to hold the posterior ends of the side arms, the dentist lifts the bow to the level of the forehead.

588 Anterior fixation
The bow is raised so that the glabella rest lies in front of the bridge of the nose. The free hand rests on the patient's forehead and gently pulls the skin tight over the bridge of the nose. With the bow pulled slightly forward, the glabella rest is pushed against the bridge of the nose and locked in place.



589 Insertion of the previously prepared transfer fork
After the transfer bow has been positioned, the customized transfer fork is seated against the maxillary teeth. The patient then closes on two moistened cotton rolls placed in the premolar regions to hold the transfer fork in place.



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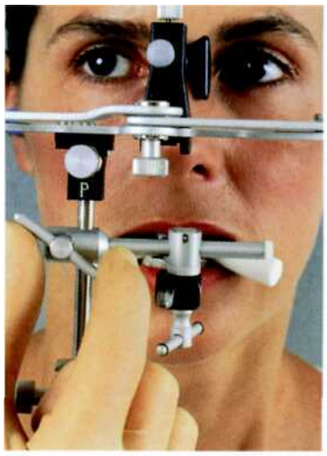
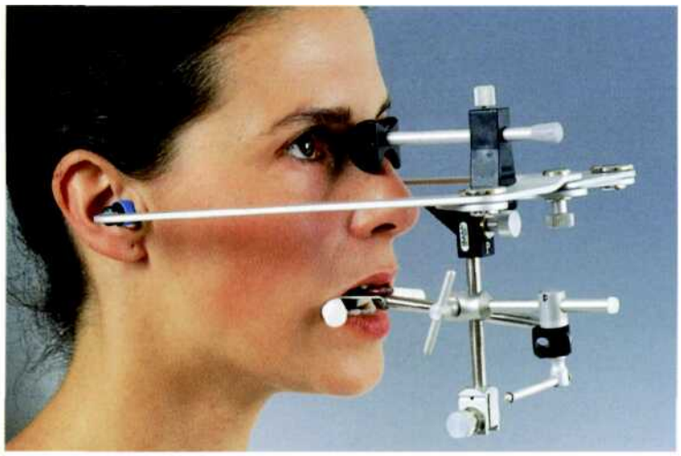
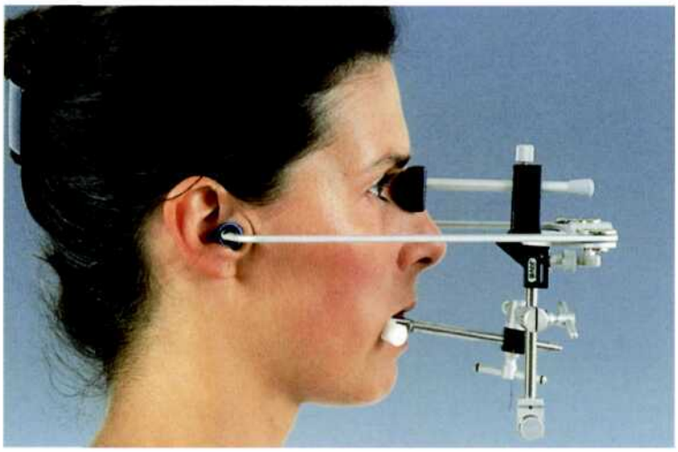


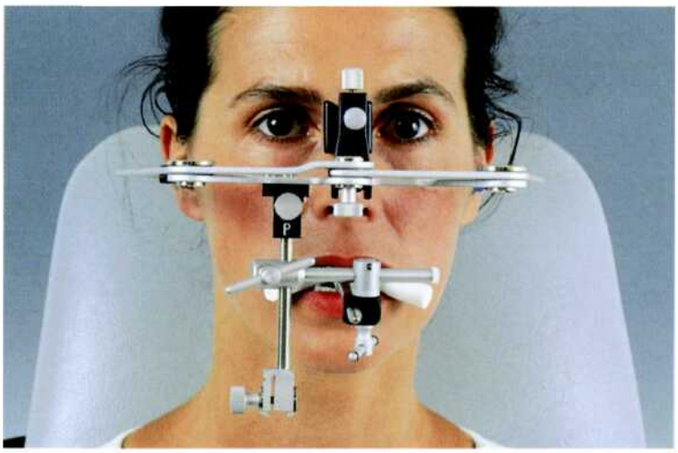


590 Adjusting the double clamp
The double and vertical clamps are loosened so that the side arm of the transfer fork holder, here Type II P, can rotate around the vertical rod and slide up or down. The double clamp is slid passively over the handle of the transfer fork.

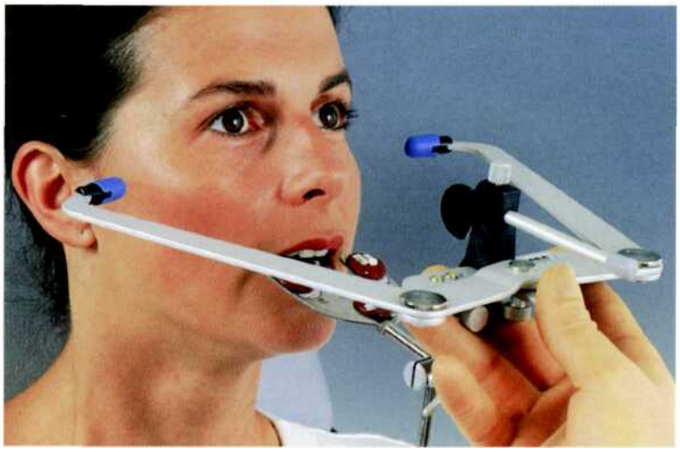
Left: The double clamps are attached to the transfer fork and to the vertical rod one after the other. The resulting torque is counteracted by applying a reciprocal torque with the other hand.



591 Lateral view of the transfer bow in place
Mounting of the transfer bow has been completed. This establishes the spatial relation of the maxillary dental arch to the arbitrary hinge axis points and to the horizontal reference plane.



592 Frontal view of the transfer bow in place
The reference plane defined by the bow lies nearly parallel with the interpupillary line.



593 Removal of the transfer bow
The side arms of the bow are spread apart by applying light pressure with the thumb as the transfer bow is carefully removed.
To ensure a stable connection between transfer fork and transfer bow during mounting of the casts, the double and vertical clamps should be carefully tightened further as soon as the bow is removed.

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Mounting the Maxillary Cast using the Anatomical Transfer Bow

After making a registration with the SAM Anatomical Transfer Bow the following methods are recommended for mounting the upper cast:

- *Indirect method:* this uses the complete face bow with the mounting stand.
- *Direct method:* mounting is accomplished by using the transfer fork carrier attached to the articulator (see p. 222).

In the indirect procedure the face bow is attached to either the upper member of the articulator or, if preferred, to the similarly constructed mounting holder. The bow is then clamped onto the special U-shaped mounting stand. Because the pegs attached to the sides of the condylar housing for receiving the earpieces of the transfer bow do not lie on the axis, the horizontal condylar inclination of the condylar housing must be set at 30°. Otherwise the mounting axis will not correspond to the arbitrary hinge axis to which the facebow was oriented on the patient. Before the cast is seated on the transfer fork, the fork should always be stabilized with plaster or the telescoping transfer fork support to prevent it from sagging under the weight of the maxillary cast and mounting stone.

594 Attaching the transfer bow to the upper member of the articulator
The holes in the ends of the transfer bow's ear pieces are slipped over the mounting pins on the sides of the articulator housings. A mounting plate is screwed onto the upper member of the articulator. There must be no gap between this plate and the articulator.

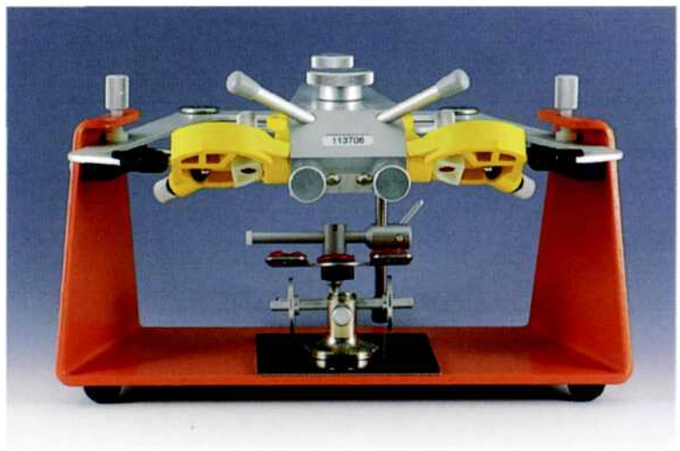
Right: The transfer bow is ready for mounting on the articulator. The blue sanitary caps have been removed from the ear pieces.

595 Use of the mounting stand
The upper member of the articulator with transfer bow attached is clamped into the mounting stand. The incisal table rests on the transfer bow.

Right: Because the lateral mounting pins are not parallel with the transverse axis of the articulator, both condylar inclinations must be set at 30° before the casts are mounted.

596 Transfer fork support
Because the transfer fork can sag under the weight of the maxillary cast, a telescoping support is placed under the transfer fork and is held in place by the magnetic pad of the mounting stand.

*Right: T*he mounting stand is turned upside down so that the telescoping support can lie evenly on the under side of the transfer fork. The transfer fork support is fixed in this position by turning the screw with the knurled knob.



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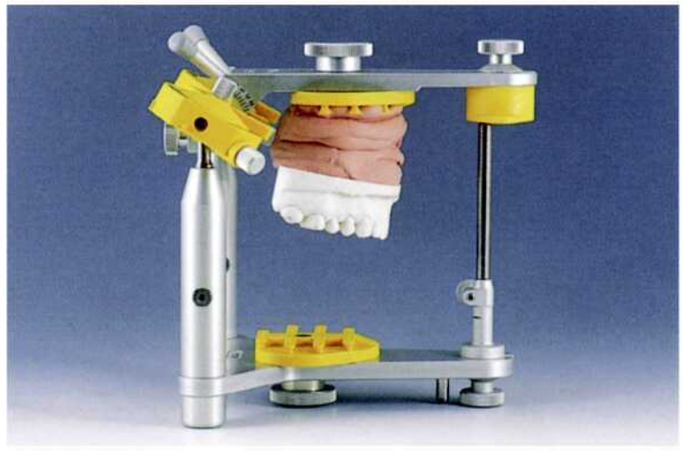
597 Seating the maxillary cast
The upper member of the articulator is rotated posteriorly, and the maxillary cast is seated completely in the cusp impressions on the transfer fork.

598 Application of the mounting plaster
Before the impression plaster or mounting plaster is applied, the basal surface of the cast should be moistened with water.
The specified water-powder ratio for the mounting stone or impression plaster to be used should always be observed.

599 Attaching the maxillary cast with plaster
The upper member of the articulator is carefully closed until the incisal table lies in contact with the transfer bow. No cracks should appear in the plaster at this time. If they do, the mounting must be repeated with fresh plaster.



600 Mounted maxillary cast
The mounted maxillary cast duplicates the spatial relationship of the teeth to the arbitrary hinge axis and horizontal reference plane that was defined on the patient with the aid of the transfer bow.

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Mounting the Maxillary Cast using a Transfer Stand

Unlike the conventional way of mounting the maxillary cast, mounting with the aid of a transfer stand does not require use of the entire facebow. The basic principle is that the transfer fork that has been adjusted on the patient can be separated from the facebow and fixed to the lower member of the articulator by means of a mounting shoe without altering its position relative to the hinge axis. The transfer fork assembly is constructed in such a way that if the horizontal reference plane is preserved, the transfer fork will now have the same spatial orientation to the mounting axis of the articulator that it had to the patient's arbitrary hinge axis when it was attached to the transfer bow. The advantage of this method is that the frame of the facebow can be disinfected immediately after being used on the patient. Then, if at least one more transfer fork carrier is on hand, the facebow is immediately available for the next patient. With some manufacturers' products, the mechanical connection between transfer fork carrier and articulator member is so stable that there is no need to place additional support under the transfer fork before placing the maxillary cast on it. Casts should always be mounted in the dental office.

601 Two-section transfer bow
If the anatomic transfer bow (from SAM) is equipped with the model IIP or model IIC transfer fork carrier, the casts can be mounted without using the actual transfer bow. For this method, the transfer fork carrier is separated from the transfer bow.

Right: On the lower member of the articulator, the incisal pin is replaced by the adapter for the type II transfer fork carrier.

602 Mouning the cast
Before the cast is attached with plaster, the condylar balls should be adjusted to their centric position. Thanks to the secure threaded connection of the transfer fork carrier to the lower member of the articulator, it is not necessary to place additional support under the transfer fork before the cast is seated.

603 The maxillary cast mounted
This method also ensures that the maxillary cast is oriented correctly to the arbitrary hinge axis and to the horizontal reference plane.

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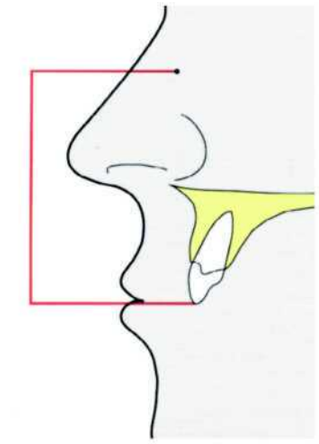
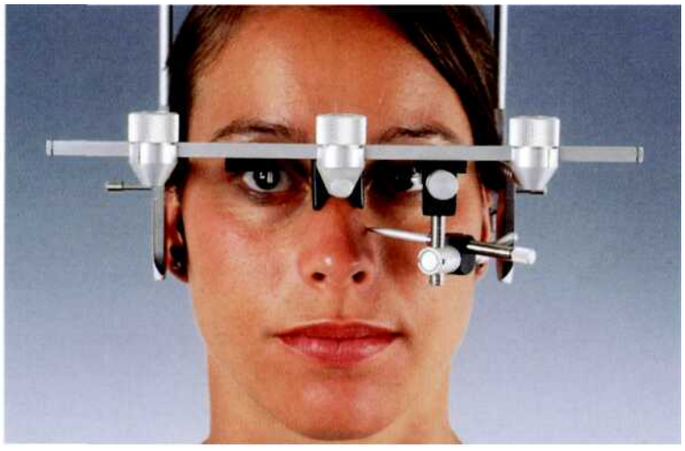
Mounting the Maxillary Cast following Axiography

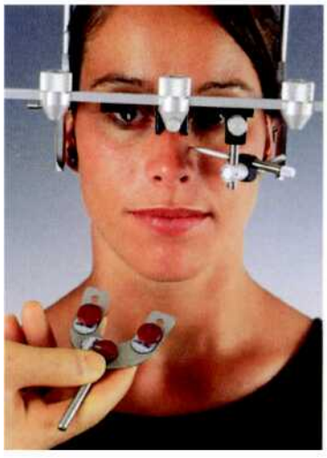
Immediately after completion of the axiography procedure (see pp. 250ff) the mandibular recording bow is removed from the flag bow and the tray clutch is removed from the mandible. During this and the following steps in the procedure, the flag bow must not be displaced from its position relative to the skull. Otherwise, the axis points marked on the graph paper will no longer lie on the hinge axis of the mandible. To correctly align the axiographic recordings obtained on the patient to the casts, it is also necessary to define a horizontal reference plane on the patient. The two recorded hinge axis points serve as the posterior reference points; the selection of a third anterior reference point needed to establish a plane is arbitrary. Orbitale or its imagined projection onto the nose has served well for this purpose. This point is fixed with the orbital pointer. The axis-orbital plane so defined corresponds closely to the Frankfort horizontal plane (porion-orbitale). Once the transfer fork carrier is placed and adjusted, the flag bow is ready for the maxillary transfer.

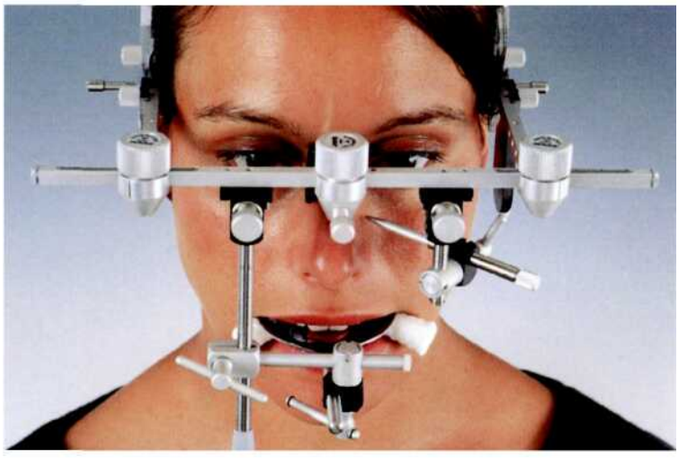




604 Preparing the flag bow for cast transfer
The orbital pointer is slid all the way onto the left dovetail of the anterior cross bar, oriented to the desired anterior reference point, and fixed in place. At the same time, the tip of the orbital pointer is covered by the end of a finger.

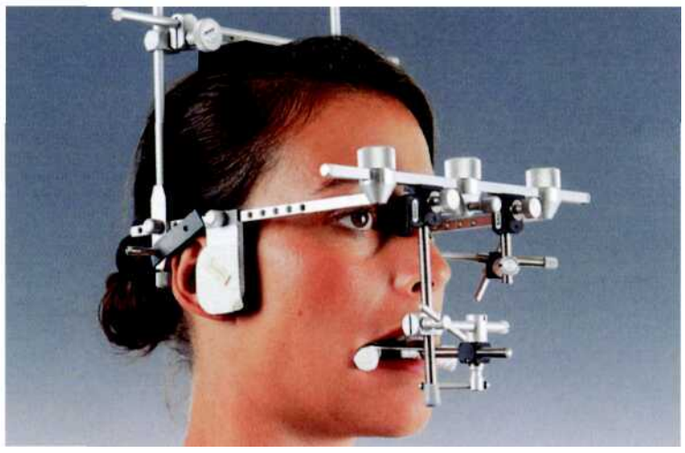
Left: The anterior reference point can also be defined as a certain distance (e.g. 50 mm) from the incisal edge of a specified anterior tooth.





605 Customizing and attaching the transfer fork
The transfer fork is adapted to the upper teeth and attached to the previously fixed vertical rod of the transfer fork carrier by means of double clamps.

Left: Impression compound or silicone putty is placed on the transfer fork to adapt it to the maxillary teeth. If necessary, the tooth imprints may be trimmed and refined.



606 The flag bow ready for cast transfer
After the flag bow has been modified for transferring the cast to the articulator, but before it is removed from the patient, it is checked to make sure all the connections are tight, especially the set screws for the side arms and the clamps connecting the transfer fork to the vertical rod of the transfer fork carrier. Next the orbital pointer is unscrewed from its sleeve and then the elastic neckband and the vertex support with its two vertical bars are removed. Finally, the flag bow with the transfer fork firmly attached is carefully removed from the patient.

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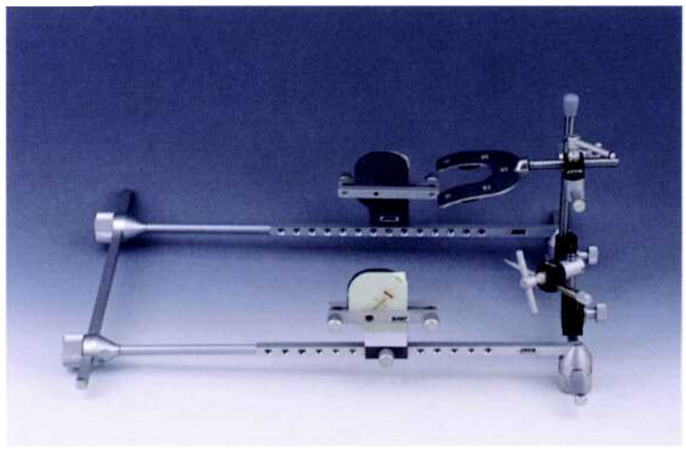
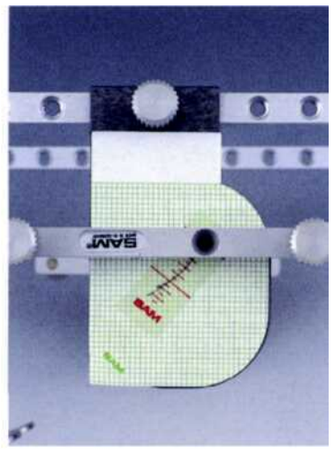
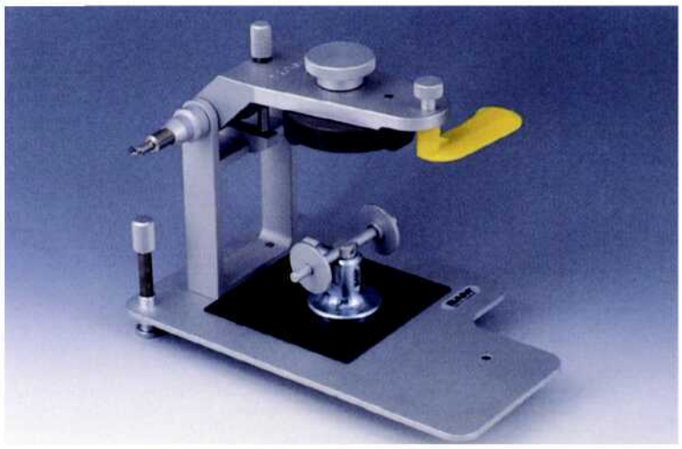
607 Preparation of the flag bow
To prevent the side arms from spreading as the flag bow is being mounted on the hinge axis mounting device, the flag arm extension rods are attached once more and connected by the posterior crossbar. The orbital pointer is replaced firmly in its sleeve.

Right The registration plate clamps are placed so that the outermost hole of each lies exactly over the dot marking the centric hinge axis.



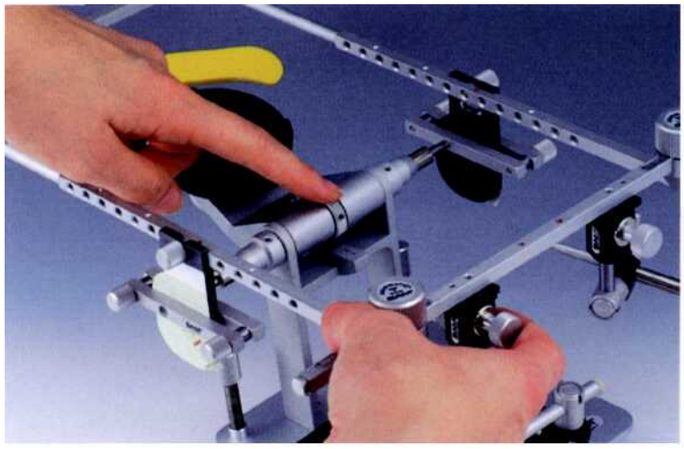


608 Hinge axis mounting device
The hinge axis mounting device (shown here with the telescoping transfer fork support) is constructed so that all parts related to cast transfer have essentially the same dimensions as the upper member of every SAM articulator.

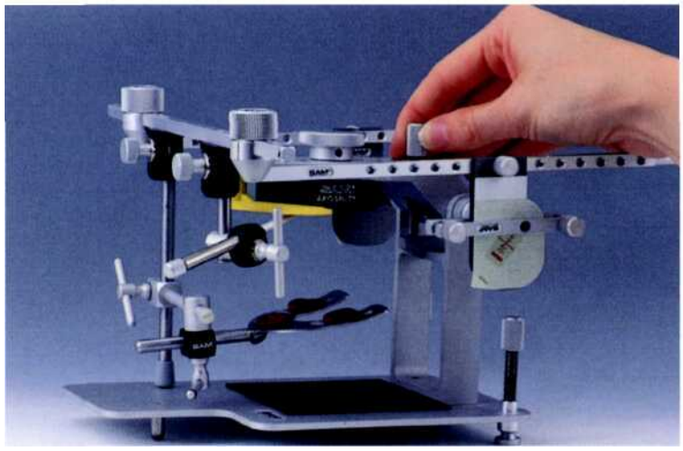


609 Mounting the flag bow on the hinge axis mounting device
The flag bow is held over the mounting device and the spindle is extended by rotating the center ring until the tips rest passively in the holes on the medial sides of the registration plate clamps.

Right: In those cases in which axiographic tracings have been made using an arbitrary hinge axis, the cast may also be mounted by using the positioning flags with ear pieces.



610 Adjustment to the anterior reference point
The upper member of the mounting device is lowered by turning the vertical screw of the spindle until the yellow reference plane lies passively on the orbital pointer. The orbital pointer can then be removed.



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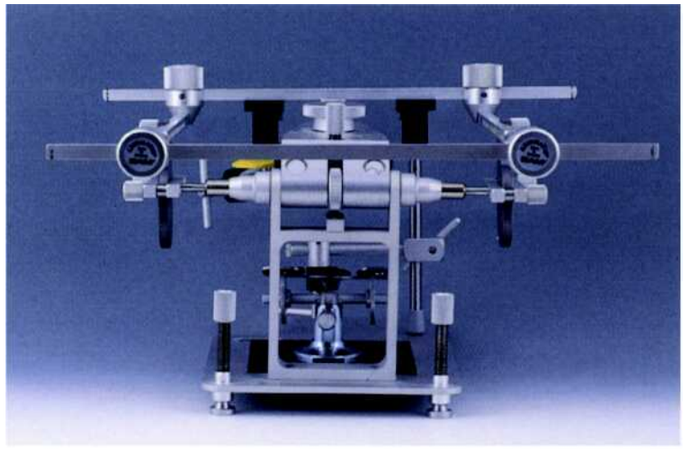
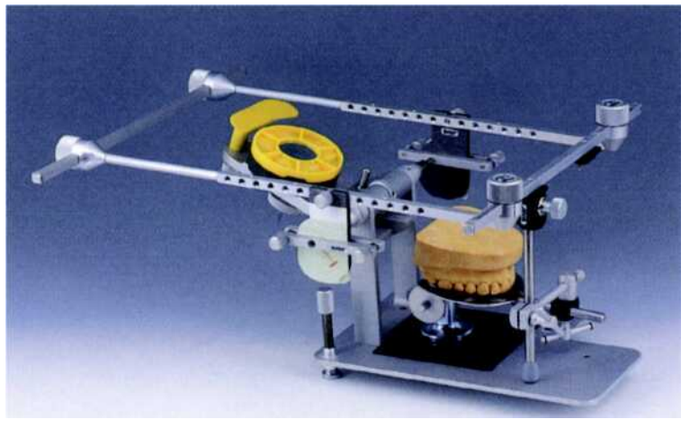
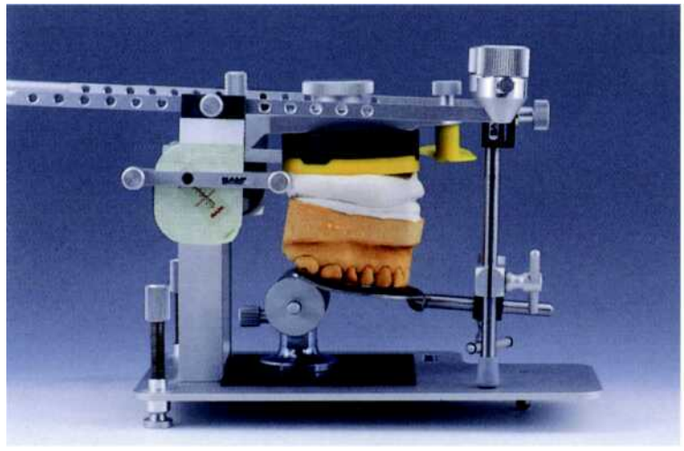


611 Supporting the transfer fork
The telescoping transfer fork support provides a quick and secure method of supporting the transfer fork before the maxillary cast is placed on it.



612 Preparation for mounting the cast
The cast is seated in the cusp indentations on the transfer fork and is ready for mounting.



613 Mounting the upper cast
The upper member of the mounting device is lowered into soft mounting stone to the predetermined height. The stone is allowed to harden free of pressure.

614 Cast transferred to the articulator
The maxillary cast has been mounted with a split-cast mounting plate and transferred to a SAM Articulator closed by the same distance.

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Mounting the Mandibular Cast

A prerequisite for a technically correct articulator mounting is that the casts are dimensionally accurate and clean with no nodules or defects on the critical occlusal surfaces. Before the mandibular cast is mounted, the occlusal record must be checked for an exact fit against both casts. If there is any indication that distortion of the occlusal record or a flaw in a cast is causing a discrepancy in the fit, the faulty procedure must be repeated. Attempting to make the occlusal record fit the casts is indulging in wishful thinking. Ideally, the casts should be hand-articulated immediately after the occlusal record is made and while the patient is still present.

If the mandibular cast is to be mounted in maximum intercuspation it is recommended that a custom vestibular plaster index be used (see p. 233).

Even though some mounting plasters have good expansion characteristics, it is preferable to use a two-stage procedure for mounting the mandibular cast. For this the condylar balls of the articulator must be centered without strain in their condylar housings. Every mounting should be tested for accuracy with the split-cast method (see p. 230).

615 Preparation for mounting
Left: The mounting stand serves both to hold and orient the upper member of the articulator. Because it is easier to mount the mandibular cast if the occlusal plane is nearly parallel with the tabletop, it is desirable in some cases to raise the upper member of the articulator.

Right The centric lock is closed on both condylar housings.

616 Two-phase mounting of the mandibular cast
Left The incisal pin is blocked open by about the thickness of the registration material (approximately 3 mm). To minimize the effect of the mounting stone's expansion, the base of the mandibular cast is first built up with a bulk of mounting stone just short of its final dimension. An appropriate thickness of packing film can be used as a spacer.

Right After the first layer of stone has hardened, the spacer is removed to leave a gap with a nearly uniform thickness of a few millimeters between stone and mounting plate.

617 Completing the mounting of the mandibular cast
Left The mandibular cast is held securely against the centric relation record with one hand while the other hand carefully closes the lower member of the articulator until the incisal pin comes into contact with the incisal table. The soft mounting stone should flow freely. If any cracks appear in it, the mounting must be repeated.

Right The maxillary and mandibular casts mounted.

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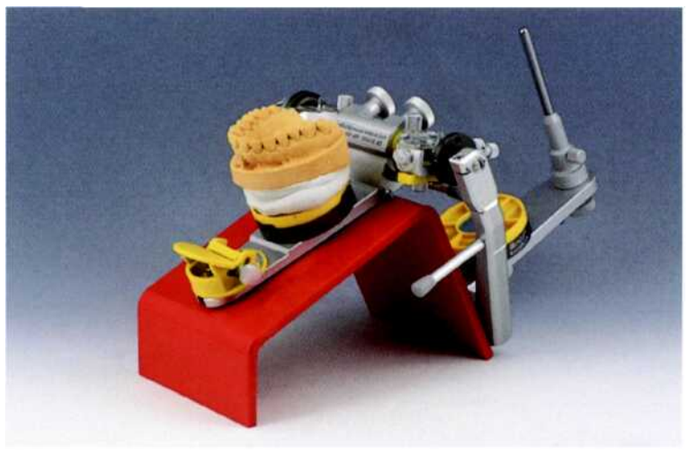
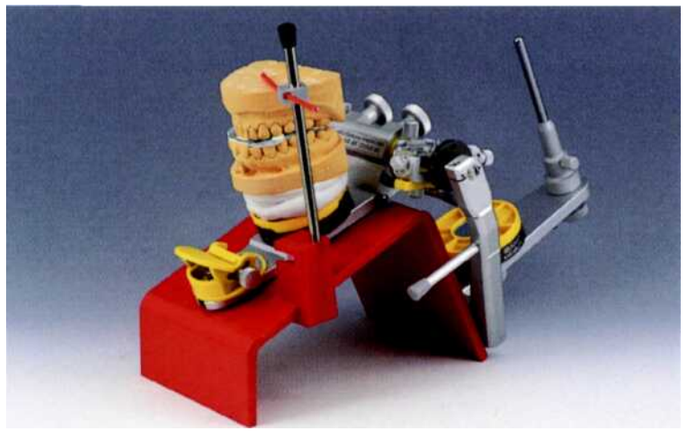
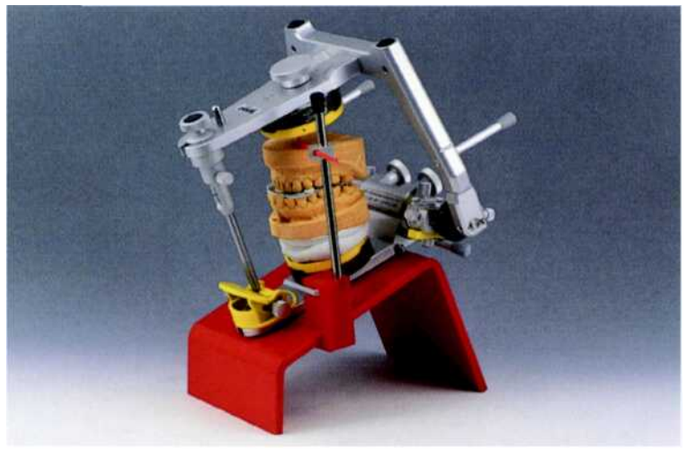


618 Using the mounting stand
Using the mounting stand facilitates mounting of the mandibular cast, especially in the SAM-3 Articulator.



619 Cast holder for stabilizing the mandibular cast
The cast holder employs a red elastic rod to help hold the mandibular cast in the centric occlusal record.



620 Trial closure of the lower member of the articulator
When the cast holder is used, the mounting is preferably accomplished in one step. In this case it is especially important to use a mounting stone with minimal setting expansion. Trial closure of the articulator helps to estimate the amount of mounting stone that will be necessary.

621 Completed mounting
Mounting of the casts in their correct relationship to the cranium and joints has been completed.
The magnetically attached Axiosplit System allows mounted opposing casts to be interchanged.

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Axiosplit System

The Axiosplit system employs a magnet-retained test base, or split-cast system for SAM articulators. This system offers the following advantages:

- Identical calibration of different articulators with similar construction
- Ease of interchanging casts
- Simple check of cast mountings
- Comparison of multiple occlusal records.

With the aid of a special adjustment key, any number of similarly constructed articulators can be calibrated identically, thereby eliminating discrepancies between the upper and lower members of each articulator. This makes it possible to move pairs of casts from one articulator to another. Thus casts mounted in the dental office can be placed in an identically calibrated articulator in the laboratory with no loss of precision. Of course, identically calibrated articulators should be rechecked regularly with the adjustment block. The magnetic retention between the primary and secondary mounting bases makes it easy to remove a cast from the articulator, and the keyed form of the mounting plate allows it to be replaced precisely.

622 Axiosplit system for equalizing the closure of articulators
1 Standard calibrating block
2 Standard incisal pin
3 Threaded plate with magnet
4 Adjusting plate with threaded base
5 Twist-lock magnet lifter
6 Yellow mounting plates with magnetically attracted keeper disks

623 Attaching the mounting plates
The Axiosplit threaded plate is firmly screwed onto the articulator's upper member and is furnished with a magnet. The brightly anodized threaded base is similarly attached to the lower articulator member. The standard incisal pin establishes the distance between the upper and lower members of the articulator. The hollow ring is already attached to the underside of the standard calibrating block by means of a magnet.

624 Placement of the lower member of the articulator
To orient and attach the hollow ring to the articulator's lower member the hollow ring is half filled with stone or a low-viscosity resin (e.g. Duralay or GC Pattern Resin).
With the centric locks open, the lower member is then seated vertically until the incisal pin makes contact.

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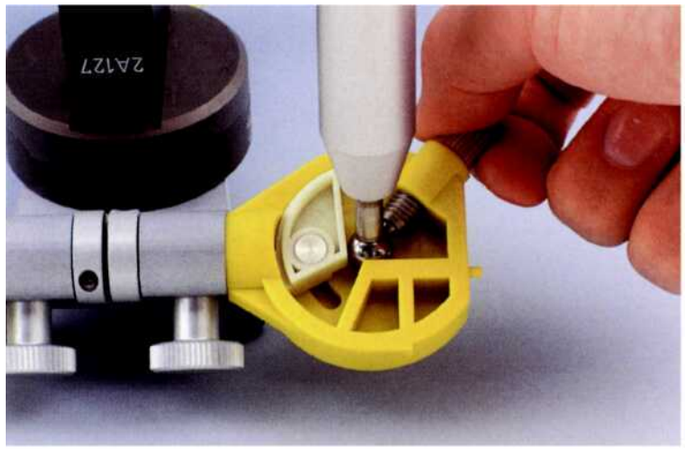

625 Fastening the centric locks
As soon as the lower member of the articulator is seated, the centric locking screws are again tightened.

626 SAM Articulator with the standard calibrating block mounted
The calibrating block establishes a precise spatial orientation of the Axiosplit mounting plates that are screwed onto the upper and lower members of the articulator.

627 SAM Articulator with keyed Axiosplit Profile plates and mounting plates
The large knurled screws on the upper and lower articulator members may be covered with black sleeves to prevent inadvertent loosening of the Axiosplit mounting plates.

628 Identical closure of similarly constructed articulators
Axiosplit calibration now makes it possible to exchange casts, even between different articulators.

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Split-Cast Control of the Cast Mounting

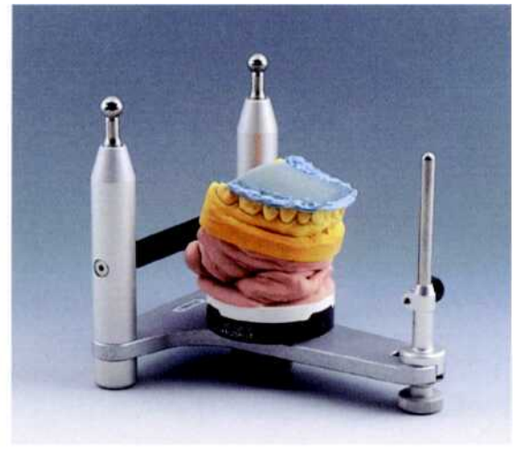
The control mounting base or split-cast method (Lauritzen 1972) complements the mounting of casts and offers the following possibilities:

- Testing of the cast mounting for freedom from stresses
- Comparison of different mounting records for agreement
- Qualitative evaluation of condylar displacement in maximum or habitual occlusion.

After the mandibular cast has been mounted the connection between the primary mounting plate, which is attached to the upper member of the articulator, and the secondary mounting plate, which is bonded to the maxillary cast, is loosened. The centric occlusal record, with which the casts were mounted, is then used to test whether the primary mounting plate can be closed against the secondary mounting plate with no gaps. If not, the mounting procedure must be repeated. A second occlusal record is proven to be identical to the centric registration used for mounting (that is, it defines the same condylar position) if it permits the primary and secondary mounting plates to close together perfectly when it is interposed between the mounted casts.

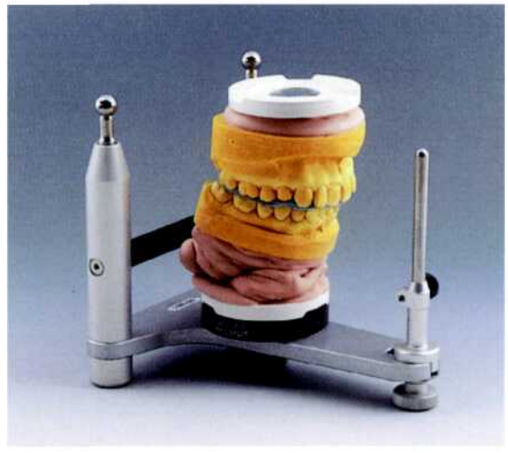
629 Preparatory steps
Left: The magnet is removed from the threaded plate with the aid of the twist-lock magnet lifter.

Right: The centric occlusal record must fit the mandibular cast precisely. Whenever the mounting of the mandibular cast is to be tested for freedom from stress, the same registration that was used for mounting must always be reinserted. The incisal pin is lowered.



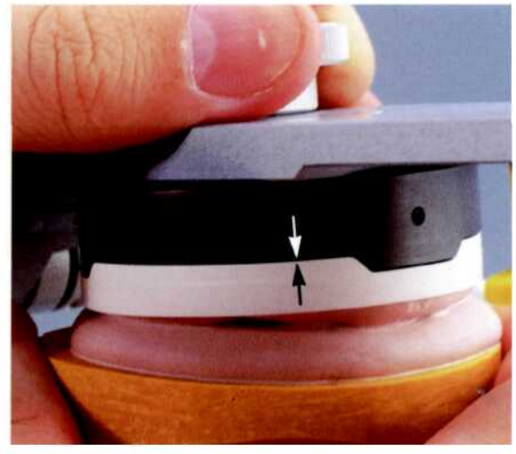
630 Positioning the maxillary cast
Left: The maxillary cast with Axiossplit mounting plate attached is placed into the tooth imprints of the centric record.

Right: The working hand secures the maxillary cast against the record and mandibular cast by applying pressure nearly perpendicular to the occlusal plane. At the same time, the other hand carefully lowers the upper articulator member with the centric lock closed.



631 Closing the upper member of the articulator
Left: The upper articulator member is closed with virtually no force until there is contact with the mounting plate. A gap-free fit of the male and female parts of the split plate indicates either a stress-free cast mounting or agreement of the tested record with the one used for the mounting procedure.

Right: The gap (arrows) seen here between the white mounting plate and the gray anodized threaded plate indicates an incongruence.



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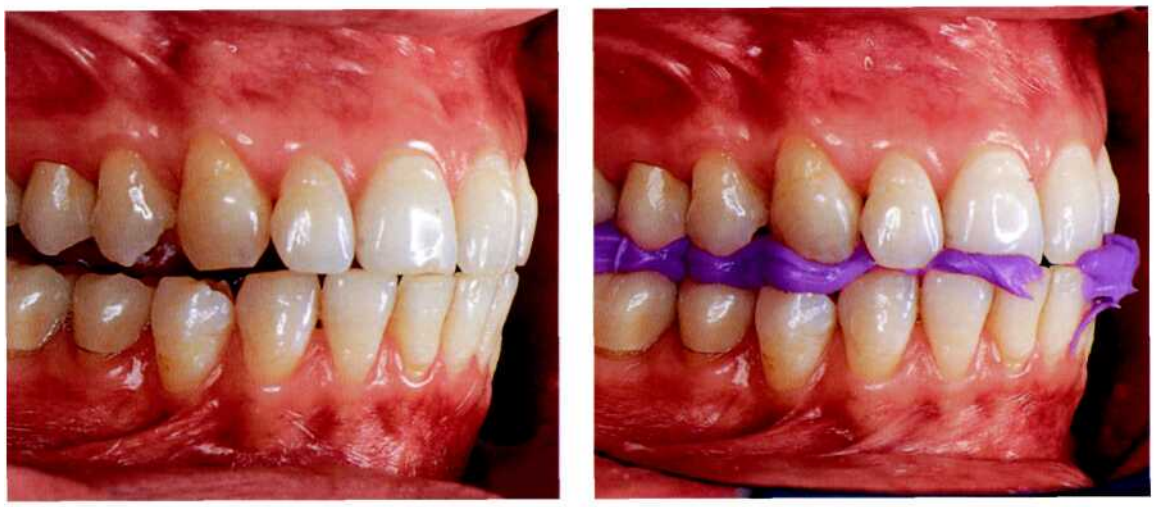
Check-Bite for Setting the Articulator Joints

The only mandibular position that the articulator can simulate directly following mounting of the casts is the jaw relation that was selected for the centric mounting of the mandibular cast. To make an approximate reproduction of the patient's dynamic occlusion, at least the sagittal condylar path of the articulator must be individually programmed. Besides registering the mandibular movements, in some cases it is advisable to make protrusive and laterotrusive check bites ("eccentric interocclusal records"). The check bites are made with the patient's teeth in positions that are relevant to the occlusion (incisal edge to incisal edge, canine cusp tip to canine cusp tip). Utilizing the Christensen phenomenon and the Bennett lateral movement, these records are then used to set the inclination of the sagittal condylar paths and the Bennett angle on the articulator. There is little agreement between lateral check bites made by different individuals, and setting the Bennett adjustment precisely is seldom successful because of the complex three-dimensional displacement of the laterotrusive condyle. Therefore it is best to limit oneself to setting the condylar inclinations with the help of protrusive check bites.

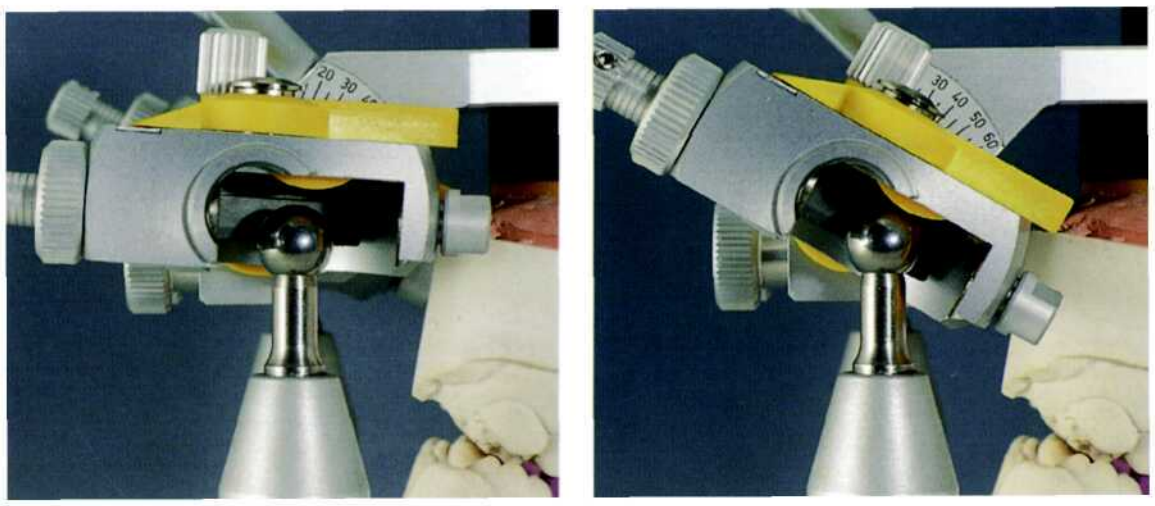


632 Protrusive check bite (interocclusal record)
Left The individually shaped anterior guidance and the sagittal condylar paths produce a definite disocclusion of the posterior teeth during eccentric movement (Christensen phenomenon).

Right: A record of the protrusive jaw relation, which is still relevant to the occlusion, can be made with a hard silicone (here: Regisil). A registration stone or a cold-polymerizing resin may also be used.

633 Positioning the protrusive check bite in the articulator
Left: The protrusive check bite is carefully trimmed and placed to fit precisely on the mandibular cast. The incisal pin is lowered.

Right: The mounted maxillary cast is seated into the tooth imprints in the protrusive record and pressed perpendicular to the occlusal plane. With the other hand, the condylar housings that were initially at the horizontal setting are rotated until each makes its first contact with its condylar ball.



634 Adjusting the sagittal condylar path
Left: The condylar housing of the articulator is still in the horizontal position. It now makes no contact with the condylar ball that is being displaced anteriorly by the protrusive check bite.

Right: The condylar housing is rotated until the sagittal pathway makes light contact with the downward and forward-displaced condylar ball. The condylar pathway, prefabricated to an average convex curvature, offers an adequate interpolation of the true condylar path.

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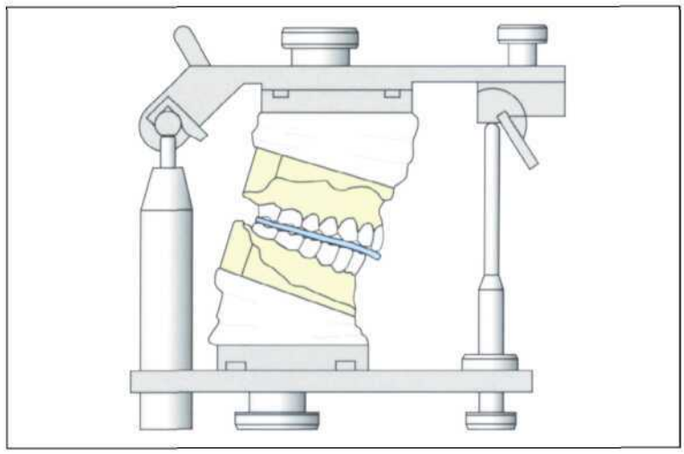
Effect of Hinge Axis Position and Thickness of the Occlusal Record on the Occlusion

With a given difference between the position of the actual hinge axis and an arbitrary transverse axis determined, for example, with the help of an anatomical transfer bow, the resulting error in the occlusion is proportional to the thickness of the occlusal record.

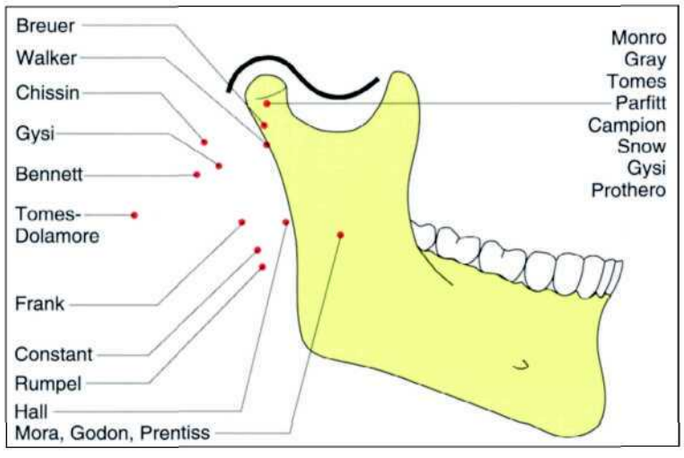
If the arbitrary axis lies superior or inferior to the true axis, the error will be greater than if the axis is misplaced anteriorly or posteriorly. Even a difference in axis location of 5 mm can result in an occlusal error of approximately 0.2 mm when the registration is 6 mm thick (Weinberg 1959). But the final clinical effect that a deviation of the path of closure has on the occlusion depends among other things upon the morphology of the occlusal surfaces, the inclination of the occlusal plane to the hinge axis, and the axial inclination of the anterior and posterior teeth.

Contacts that are artificially misplaced have less of an effect in a dentition that is heavily abraded than in a dentition that has steep, close-fitting cusp inclines. Nevertheless, experience has shown that mountings made by using an arbitrary facebow to orient the casts to the joints are sufficiently accurate, provided that the centric occlusal record does not separate the teeth by more than 3 mm.

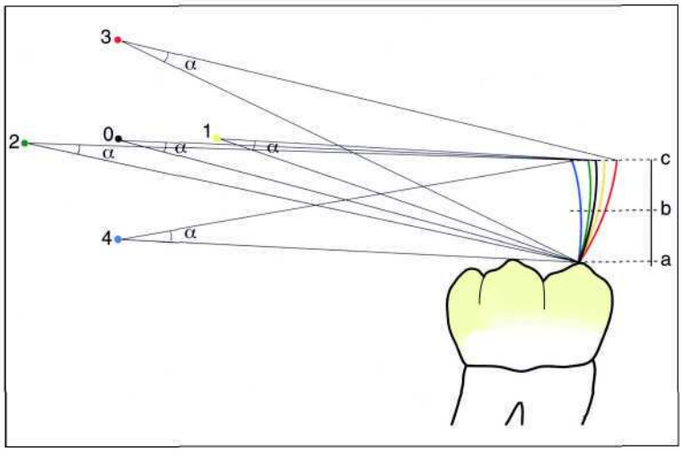
635 Interocclusal record
In the majority of cases, an interocclusal record causes a greater or lesser degree of "bite opening" that ordinarily must be compensated for by a corresponding lowering of the upper member of the articulator. This can be done with precision only if the mounting axis on the articulator is coincident with the initial rotational axis of the patient.



636 Various reported locations of the hinge axis relative to the mandible
In the literature, numerous different descriptions are given for the transverse hinge axis of the mandible (Bosman 1974). These differences arise essentially from the different techniques used for determining the hinge axis. As the amplitude of the opening movement increases, the resulting axis of rotation is displaced from the condyle posteriorly or inferiorly. Within the range of clinically relevant initial opening and closing movements, however, it does actually lie in the condylar region.



637 The effect of incorrect location of the axis and the thickness of the interocclusal record on the occlusion
This schematic drawing in the sagittal plane illustrates that occlusal errors can depend on both the separation caused by the occlusal record (a-c or b-c) and the discrepancy between the arbitrary hinge axis and the patient's true hinge axis (1-4). If the incorrectly located axis is superior (3) or inferior (4) to the actual axis, the occlusal errors will appear greater than if the discrepancy is purely anterior or posterior (1,2).



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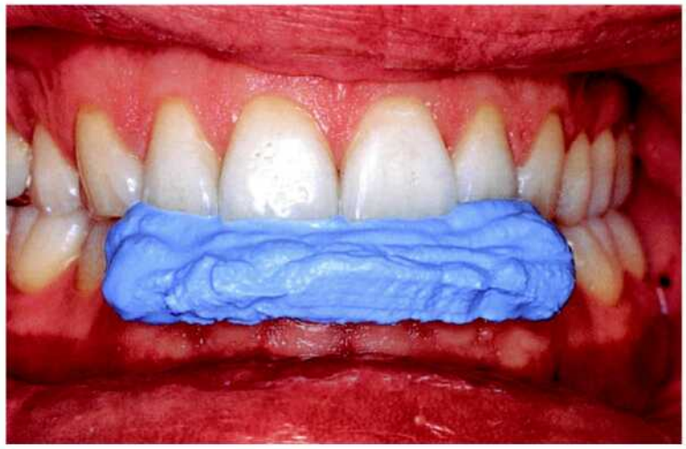
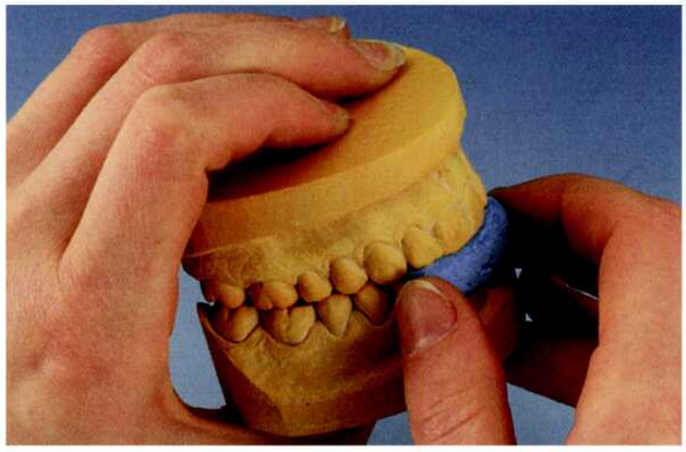
Occlusal Analysis on the Casts

An occlusal analysis on mounted casts is very important for occlusal diagnosis, treatment planning, and monitoring of treatment. It makes it possible to make repeated studies of the occlusion on rigid stone casts and to perform trial occlusal modifications while separated from the patient in time and space.

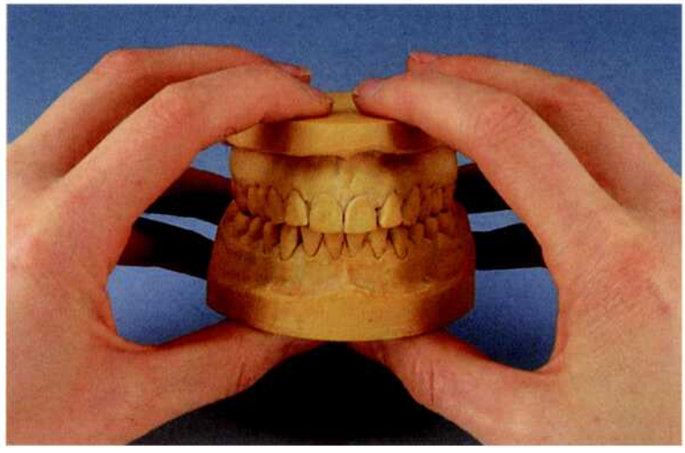
The minimum requirements of a correct instrumented occlusal analysis are dimensionally accurate casts of the dental arches mounted on a semiadjustable articulator in the correct relationship of the maxilla to the cranium. The articulator should allow at least the condylar paths to be individually adjusted with a protrusive check bite (see p. 231). Because the relevance of the instrumented occlusal analysis to the clinical situation depends essentially on the quality of the centric occlusal record, an analysis made before the conclusion of successful preliminary treatment can serve only for orientation. Ambiguous jaw relations that are reproduced in the articulator are often the *result* of protective jaw positioning and are not necessarily the *cause* of muscular dysfunction or condylar malposition.



638 Recording the maximum intercuspation position
To facilitate later orientation of the maxillary and mandibular casts in maximum intercuspation, an index is made by applying a registration stone (here: Centridur) to the facial surfaces of the teeth as the patient holds the mandible in the maximum intercuspation position without exerting force.



639 Occluding the stone casts in maximum intercuspation
The stone index is carefully trimmed and then used to help fit the casts together in an accurate reproduction of the clinical jaw relationship.



640 Evaluating occlusal stability
The stone index is removed and the casts are pressed together, alternating the load between the molar and premolar areas.
Assuming that the casts are dimensionally accurate, any rocking indicates that the patient's maximum intercuspation is unstable.
Such a finding on the casts can he confirmed or disproved in the mouth with the help of shim stock.

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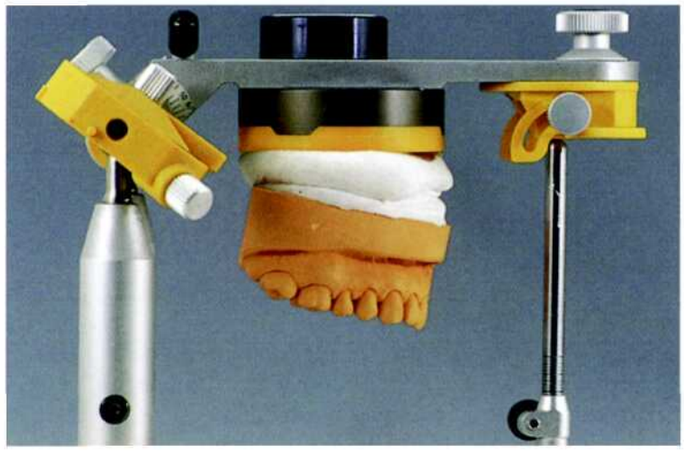
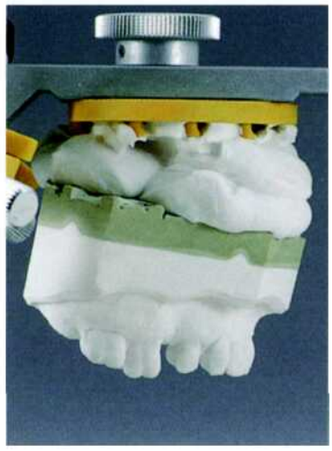
641 Evaluating the occlusal plane and the compensating curves

The compensating curves of the maxilla and the mandible are evaluated separately for contours and bilateral symmetry. The spatial relationship of the occlusal plane and compensating curve to the sagittal condylar path and the anterior guidance can give the first indications of susceptibility of the dynamic occlusion to disturbances.

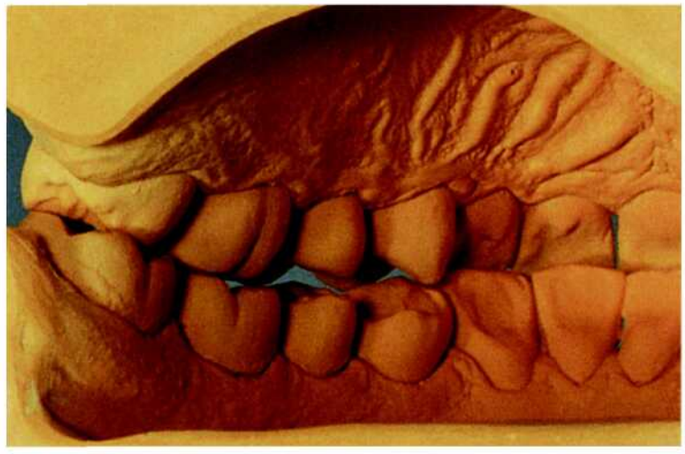
Right: Occlusal interferences can be expected in this example with missing and elongated teeth.





642 Evaluating the occlusal relationships from the lingual

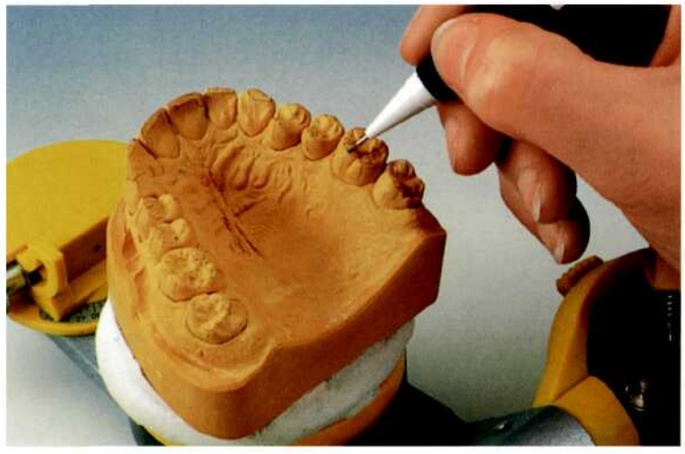
One of the most decisive advantages of occlusal analysis on casts is the ability to study the relationship of occlusal contacts from the lingual aspect.



643 Marking the load-bearing and non-load-bearing cusps

Cusp ridges and cusp tips are marked with a pencil. The position of each cusp tip is also indicated by lines projected onto the buccal and lingual surfaces of the tooth.

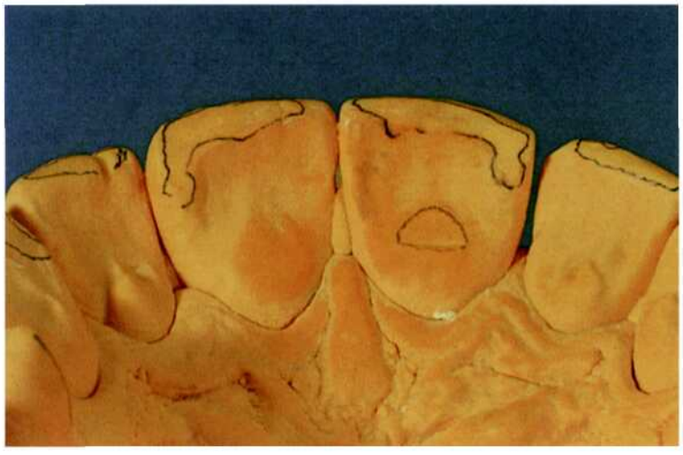
Right: The lines reveal the positional relationships between the upper and lower buccal cusps in centric occlusion.



644 Outlining the abrasion facets

The outlines of the abrasion facets are traced with a sharp pencil.

The direction of tooth-guided parafunctional activities can be deduced from the arrangement of the facets in relation to the individual functional structures of the teeth. A final differentiation of abraded surfaces into active facets that are still brought into contact by the patient, and inactive facets that no longer fit together can be made only through intraoral examination.



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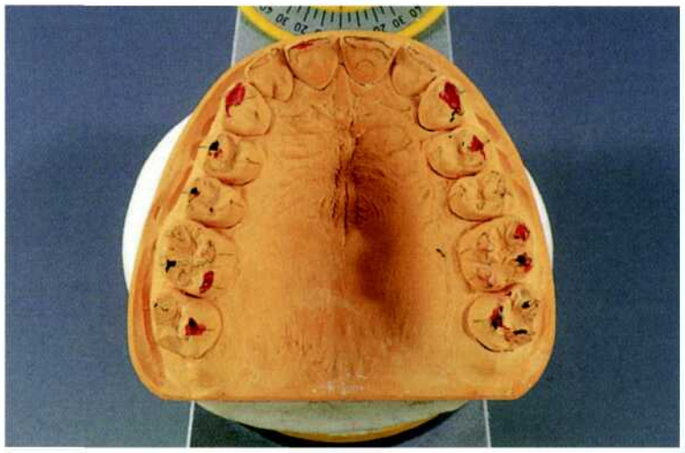
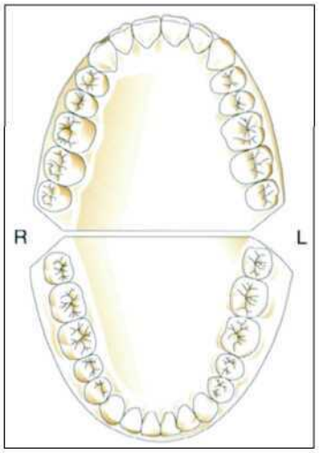
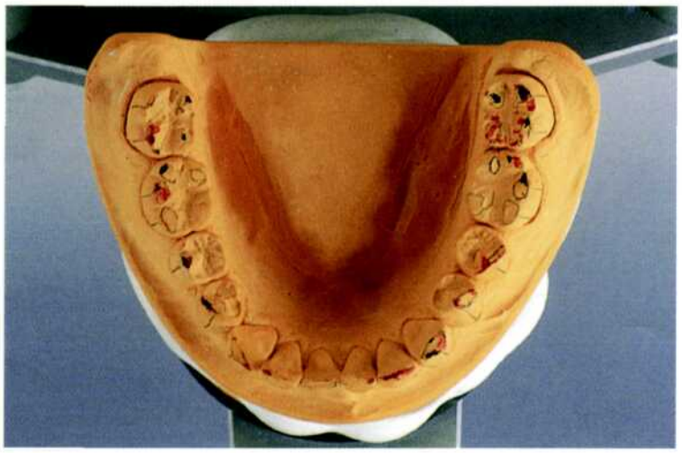
645 Marking centric occlusion
The condyles are locked in centric and the incisal pin is lowered. Then the centric occlusal contacts are marked with black articulating paper that marks on both sides.

646 Marking eccentric occlusion
The centric set screws of the articulator joints are loosened. The dynamic occlusion is carefully checked with tooth-guided eccentric movements. The mediotrusive (nonworking), laterotrusive (working), and protrusive contacts are marked with red articulating paper. *Left:* When the upper member of the articulator is guided properly, the mediotrusive condyle maintains continuous contact with the Bennett guiding surface. In addition, both condyles slide along the superior surfaces of the articulator housings.



647 Centric and eccentric contact pattern on the maxillary cast
The occlusal markings indicate inadequate occlusal support in the posterior region. The eccentric guidance for the mandibular teeth is uneven and shows dominance in the molar region.





648 Occlusal contact pattern on the mandibular cast
Most of the eccentric contacts do not coincide with the outlined wear facets. This indicates that tooth-guided parafunctional movements also start from maximum intercuspation.

Left: Sample from an examination form on which the current pattern of occlusal contacts can be documented.

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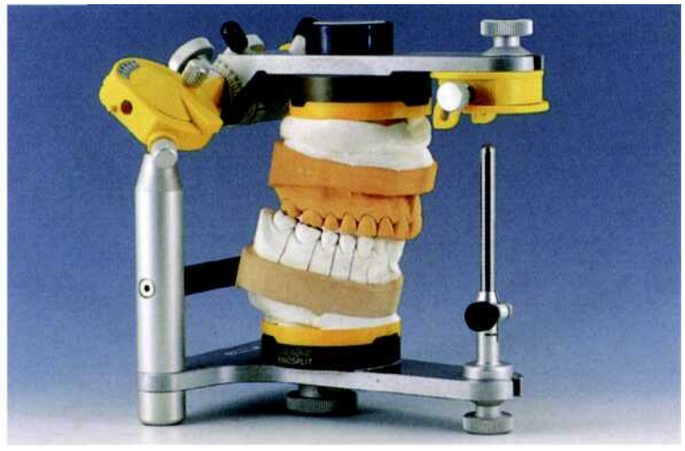
Occlusal Analysis Using Sectioned Casts

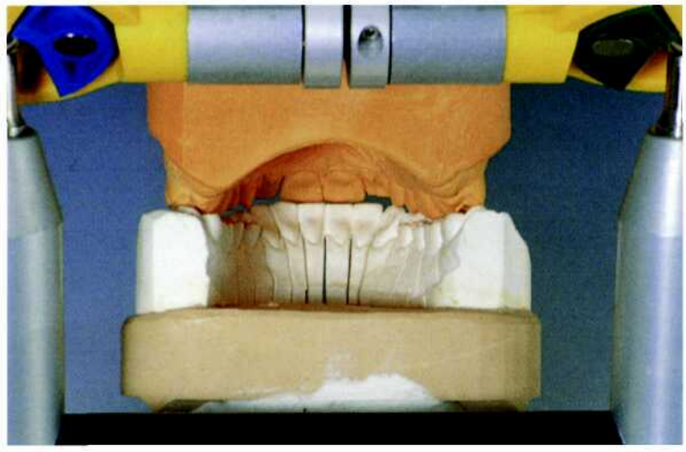
With the help of a sectioned mandibular cast with removable teeth mounted in centric it is possible to repeatedly experiment with alterations of the occlusion through selective reduction of the teeth. With this method one can calculate, before cutting away any of the occlusal surfaces of the stone casts, approximately how much tooth structure would have to be removed to achieve the desired equilibration. A step-by-step analysis can be made on the mounted casts to determine how the planned corrections would affect the cuspal relationships and the vertical dimension. At this stage, then, it is possible to foresee whether the occlusion can be stabilized through selective grinding alone or if prosthodontic or orthodontic measures will also be necessary. In some cases we also use occlusal analysis on sectioned casts as a tool for explaining the proposed treatment to the patient. The reasons for the planned occlusal reshaping of the natural teeth and the changes that can be expected must be thoroughly discussed with the patient.

649 Materials for occlusal analysis with the help of a segmented cast
Maxillary and mandibular casts are mounted in a relationship to the articulator corresponding to that of the natural teeth to the cranium and joints. The segmented mandibular cast with removable teeth has also been mounted in centric and thus is interchangeable with the solid mandibular cast. Strips of shim stock cut to the width of a premolar are used to test the occlusal contacts.
All of the posterior teeth and at least the lower canines should be removable as individual segments.

650 Centric occlusion
The segmented mandibular cast has been substituted for the solid mandibular cast.
The upper member of the articulator is closed to the first occlusal contact.
Preliminary inspection suggests that occlusal equilibration by selective grinding could be accomplished only with considerable loss of tooth structure in the molar region.



651 Lingual view of the teeth in centric occlusion
In this lingual view the functional open bite in the premolar and anterior region becomes especially apparent.



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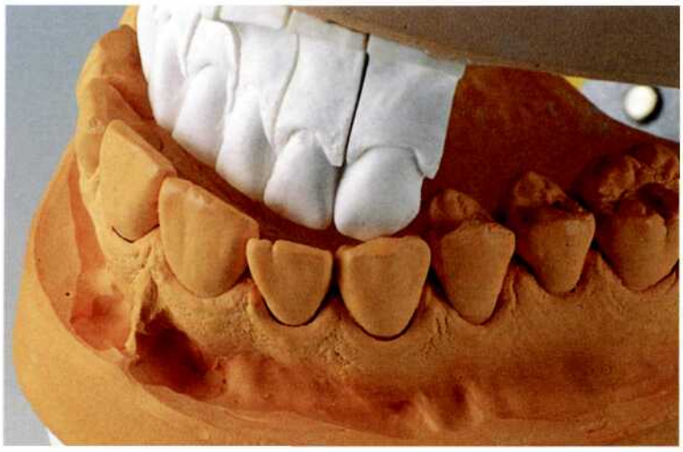
652 Shim stock test and removal of the interfering segments
The pair of teeth making premature contact is located with the help of shim stock, and the corresponding tooth is removed from the mandibularcast.

Left: Before the first tooth segment is removed, the setting of the incisal pin with the assumed premature centric contact is read from the millimeter scale (here -1 mm). This number is recorded for further evaluation.

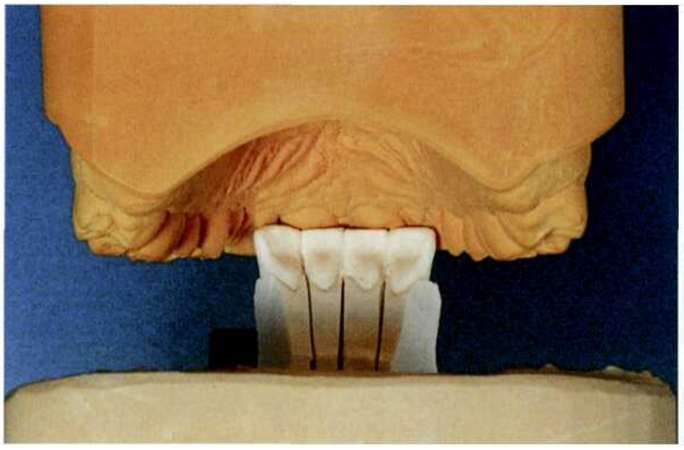
653 Further shim stock tests
Following elimination of the posterior occlusion in this example, the sole remaining tooth contact is found in the right canine region.

Left The incisal pin setting after removal of all posterior tooth segments (here+1 mm).



654 Occlusal discrepancy in the anterior region
The only remaining centric premature contact now lies on the lingual guiding surface of the maxillary right canine. The anterior horizontal overlap is still too great to allow an initial incisal guidance.

Left: Corresponding situation on the opposite side.



655 Occlusal relationship after removal of both mandibular canines
Not until both lower canines were removed could the incisors make simultaneous contact after further lowering of the upper member of the articulator.

Left: Final setting of the incisal pin (here: +3.5 mm). Thus, in this case, it was necessary to close the articulator by 4.5 mm to eliminate all premature contacts.

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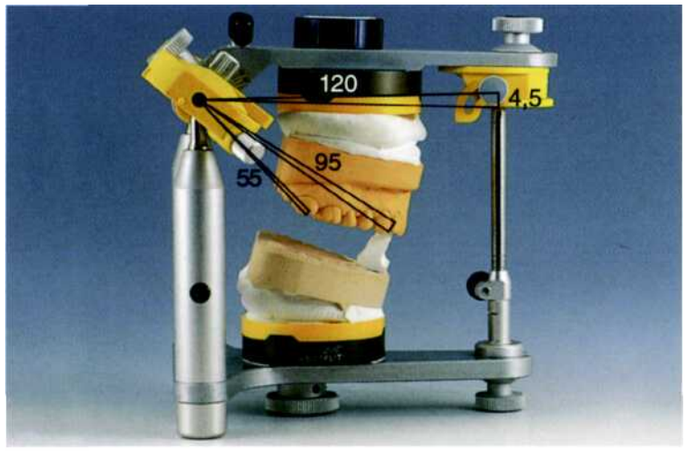
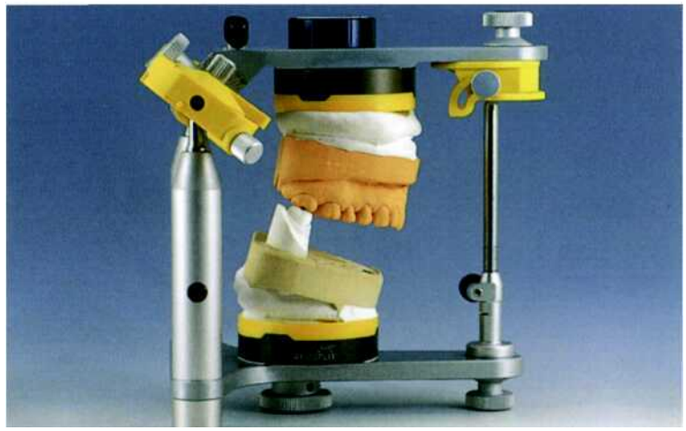
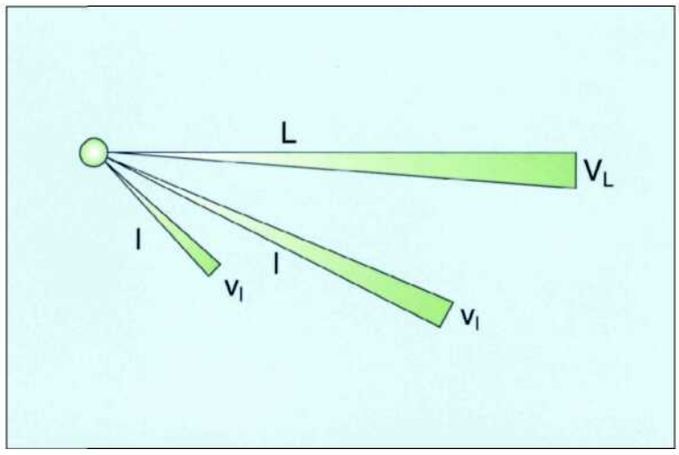
656 Premature centric contact and setting of the incisal pin
In this case the first centric contact was between the opposing right second molars. The incisal pin is set at -1 mm. The other segments of the cast have been removed for clearer presentation.



657 Evaluating the effect of vertical changes on the occlusion
The desired pattern of contacts on the incisors was not achieved until all posterior tooth contacts were removed. The incisal pin setting is now at +3.5 mm. The reduction in vertical dimension measured at the incisal pin (V_L) is therefore 4.5 mm. The occlusal reduction for each pair of opposing teeth can be closely calculated. In this case, the occlusal reduction in the molar region necessary to restore anterior tooth contact is approximately 2.1 mm. (All measurements in the illustration are in millimeters.)



658 Calculation of the approximate amount of occlusal tooth structure to be sacrificed
Left: The line L represents the distance from the axis of the articulator hinge to the tip of the incisal pin. V_L is the loss in vertical dimension measured at the incisal pin. I is the distance from the condyle to a given occlusal premature contact (in this and the preceding illustration, 55 mm and 95 mm). The amount of occlusal reduction V_I is arrived at by the formula to the right.
Right: Formula for calculation of the approximate amount of occlusal height lost through grinding adjustments in centric occlusion.

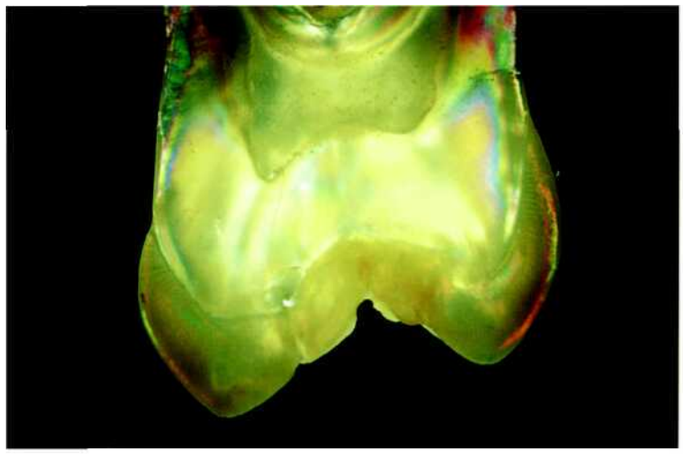


$$\frac{V_L \times I}{L} = V_I$$

659 Longitudinal facial-lingual tooth sections
Left: Facial-lingual section through a maxillary molar. The average thickness of enamel on nonabraded molars is 1.45 mm and on premolars 1.4 mm (Chediak 1967).

Right: Facial-lingual section through a maxillary central incisor. The small thickness of enamel on incisor teeth does not allow extensive equilibration by grinding, but only light lingual and incisal refinements.

Collection of W Kohler



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Diagnostic Occlusal Reshaping of the Occlusion on the Casts

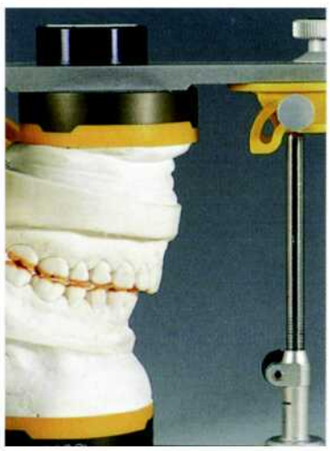
Diagnostic equilibration allows precautionary planning before irreversibly altering the occlusion. Its aim is essentially the elimination of premature centric and eccentric contacts (Motsch 1978). Whether and to what extent selective grinding in the patient's mouth can result in a stable occlusion free of interferences can be evaluated with the necessary degree of certainty only with the help of correctly mounted diagnostic casts! With these casts the necessary corrections can be rehearsed by selectively cutting away the premature contacts in stone. In a case where the occlusion is supported by the anterior teeth, one should never attempt to compensate for an infraocclusion of the posterior teeth (concealed loss of the support zone) by relieving the anterior tooth contacts. Sometimes selective reduction must be supplemented by an occlusal waxup (see pp. 234ff).

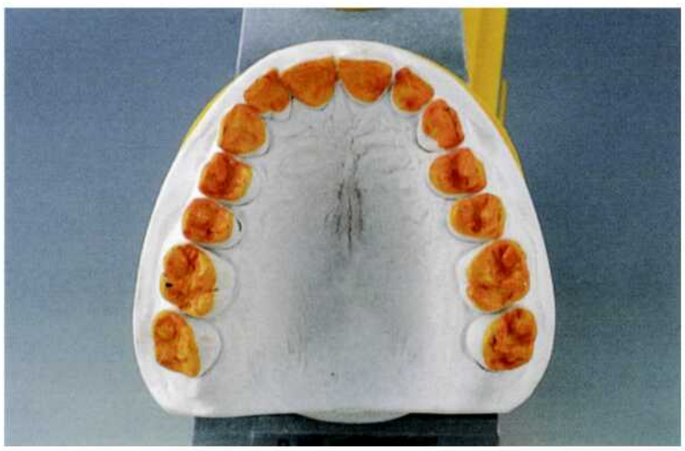
Occlusal reshaping of the natural teeth is carried out step by step by following a "check list." This check list and the pattern of cuts established on the casts are to serve only as reference aids and should not be automatically transferred to the patient's dentition without reflection.

660 Materials for occlusal adjustments on mounted casts
Individually adjusted articulator with casts mounted to duplicate the relationship of the natural teeth to the temporomandibular joints. Also ready are articulating paper forceps with shim stock and different colored articulating paper, yellow felt-tipped marker (Edding 3000), pencil, and an X-Acto knife.

661 Coloring and marking
Left: Prior to marking and relieving the premature occlusal contacts, the functional occlusal surfaces of posterior teeth plus the lingual and incisal guiding surfaces of the anterior teeth are colored with the yellow felt-tipped marker.

Right: After the teeth are colored, the articulator joints are locked in centric and the incisal pin is taken out of contact.
Next the centric contacts are carefully marked by tapping the teeth on black articulating paper.





662 Premature contact and vertical incisal pin setting
The first occlusal contact, here on the opposing right first molars, is noted.

Left: The vertical setting of the incisal pin at the initial occlusion is likewise noted.

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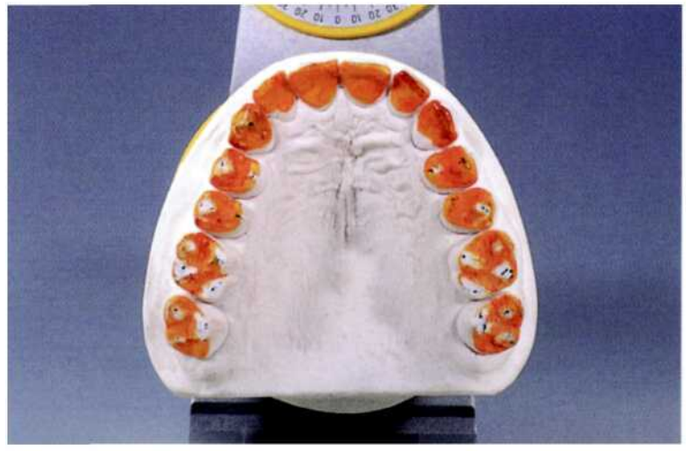
663 Relieving the premature centric contacts
The marked early contact is trimmed away with the X-Acto knife.

Right: The reduction in vertical dimension resulting from each step of equilibration is read from the incisal pin and recorded.

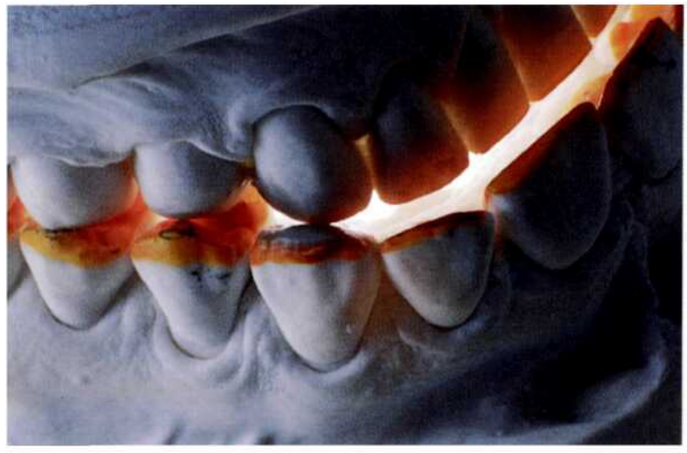
664 Equilibrated posterior occlusion
Appearance of the occlusal surfaces after achieving an acceptable pattern of contacts in the posterior region. The upper and lower right canines are also already in contact. In this case, additional anterior contacts could be realized only by excessive reduction of the occlusal surfaces of the molars.

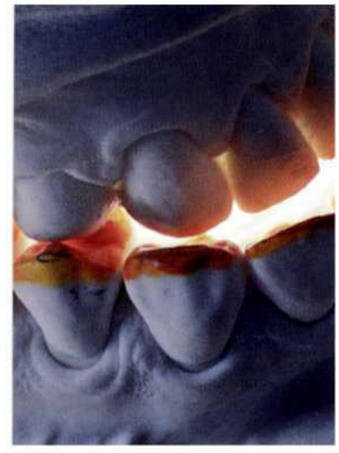
Right: Corresponding setting of the incisal pin.



665 Correcting the dynamic occlusion through a diagnostic waxup
Right: In spite of the occlusal equilibration of the posterior teeth, there is still no anterior guidance or even canine guidance.

Left: By building up the occlusion in wax, it can be clearly seen how the guiding surfaces of the left upper and lower canines must be built up to create at least a bilateral canine guidance. By using the adjustable incisal pin, the inclination of the guiding surface on the upper right canine can be transferred to the upper left canine.





666 Testing the eccentric occlusion
Marking the eccentric occlusal contacts.

Right: The canine guidance ensures disocclusion of all the other teeth.

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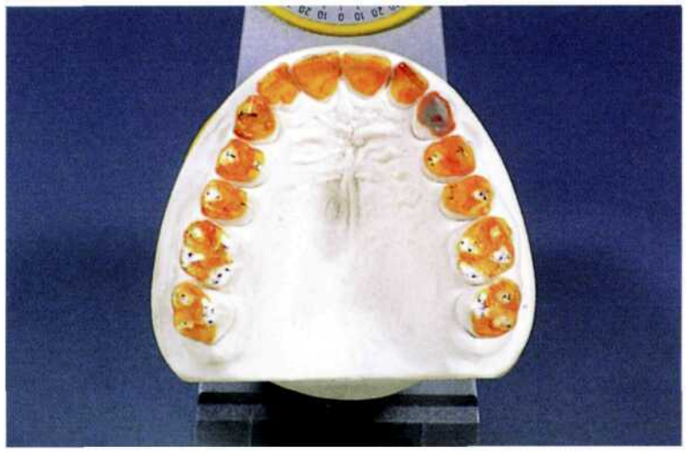
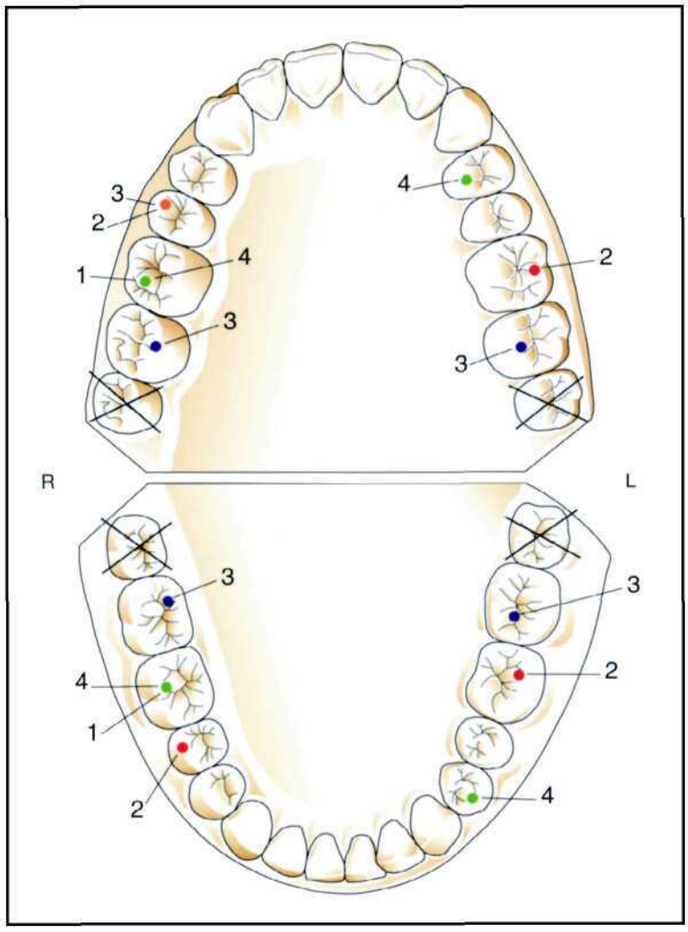


667 Completed diagnostic equilibration on maxillary cast
The areas that have been adjusted can be easily differentiated from the "undisturbed" occlusal surfaces that retain their yellow surface coloring.

668 Corrected mandibular cast
The situation is analogous to that seen in Figure 667.



669 Record of the individual equilibration steps
The very first corrective cuts on the occlusal surfaces of the casts should be carefully recorded.
The individual contacts that appear at each test of the occlusion are marked with the same number: 1 for the premature contact before the first adjustment is made; 2 for the new contacts appearing after the first correction, etc.
These groups of occlusal contacts should develop in the same way during the selective grinding procedure in the patient's mouth. If they deviate from the pattern of adjustments made on the articulator, the equilibration procedure should be interrupted to investigate the cause of the discrepancy between the laboratory and intraoral findings.

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Diagnostic Tooth Setup

In orthodontics rearrangement of the positions of teeth in a cast is referred to as a "setup" (Miura 1966, Boersma 1970). Its purpose is to evaluate the extent to which the teeth can be moved within the dental arch independently of diagnostic selective grinding and diagnostic waxing. This is of special interest in cases that are to be treated through a combination of surgery and orthodontic treatment. The setup makes it possible to determine what percentage of the existing malocclusion can be corrected orthodontically and how much of it will have to be treated through surgery. At the same time it helps to define the goal of presurgical orthodontic treatment. Another indication for a diagnostic setup is the fabrication of a positioner for refining the occlusion after removal of the fixed orthodontic appliance (Lew 1989). After the desired tooth position is achieved in the setup, the cast is duplicated and a special thermoplastic sheet (by Scheu Dental) is vacuum formed over it. By using an elastic material, greater orthodontic tooth movement can be achieved (Hinz 1991). Recent developments make computer guided setups possible (Motohashi and Kuroda 1999).

670 Starting conditions
Lateral view of the occlusion in the left posterior region of a 17-year-old female patient. This is the initial condition before combined orthodontic and surgical treatment. There is a distocclusion in both the posterior and canine regions by the width of one premolar. In addition to a transverse deficit in the maxilla, the upper incisors are tipped anteriorly and this increases the anterior horizontal overlap even more.

671 Maxillary setup
To produce a setup cast, a silicone impression of the dental arch is poured with a hard dental stone (Type IV). After it has hardened, the stone dental arch is removed from the impression and sectioned by saw-cuts made in the base directed toward the interproximal spaces. The replicas of the individual teeth are then placed back in the impression without pins. Next, molten wax is poured into the impression, covering the stone to a depth of approximately 2 mm. Finally, a base of mounting stone is poured over this.

672 Occlusion of the diagnostic setup
Both setup casts are mounted in an articulator with the help of a facebow transfer and a conventional centric registration. Then orthodontically feasible tooth movements are made. Frequently, this will worsen the malocclusion in the articulator. However, if the casts are placed together by hand, one can get a preview of how the occlusion will look after successful orthognathic surgery. This process helps to determine the magnitude of dental and skeletal movements that will be necessary.

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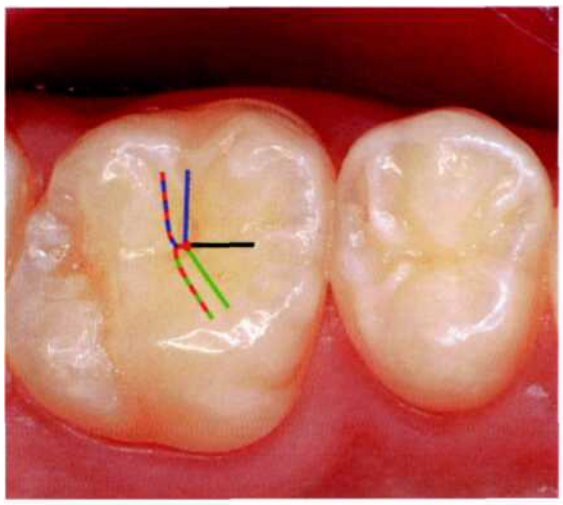
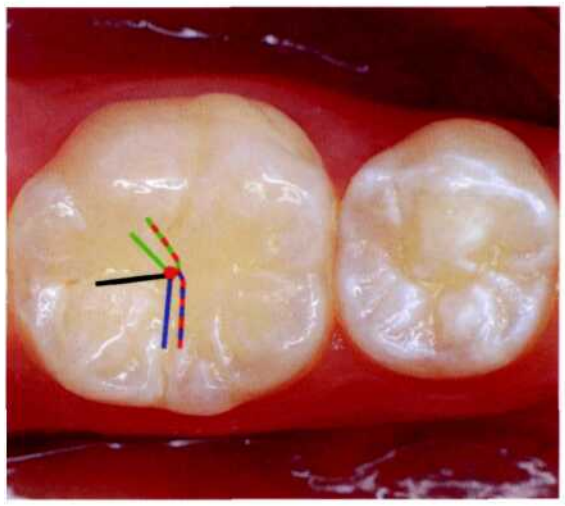
Diagnostic Waxup

In addition to diagnostic occlusal subtractive reshaping and the diagnostic setup, a diagnostic waxup can help in the planning of definitive occlusal modifications. In some cases it may be necessary to combine all three of these diagnostic procedures. Correctly mounted casts are necessary for a diagnostic waxup. As a rule, this procedure is indicated only after preliminary treatment has been successfully completed. In individual cases, the waxup can provide the answer to the question of whether or not additional procedures will allow the preferred occlusal concept to be realized in harmony with the occlusal curve and esthetic demands. If there is a pronounced Bennett movement with a distinct superior or posterior component, it may not be possible to achieve three-point cuspal contacts without interferences, even with an initial canine guidance. These cases are indications for the "biomechanical waxing technique" by Polz (1987) and the "natural waxing technique" by Schulz (1992) based upon the former. The diagnostic waxup also helps in estimating the placement of the preparation finish lines and the amount of tooth reduction that will be necessary for fixed restorations.



673 Functional chewing surfaces in the maxilla
Left: Undamaged natural maxillary premolar and molar. The functional paths of the tip of the distobuccal cusp of the lower first molar are superimposed as color-coded lines over the occlusal surface of the upper first molar. Black = protrusion; blue = laterotrusion; green = mediotrusion; red-green = retromediotrusion; red-blue = retrolaterotrusion.

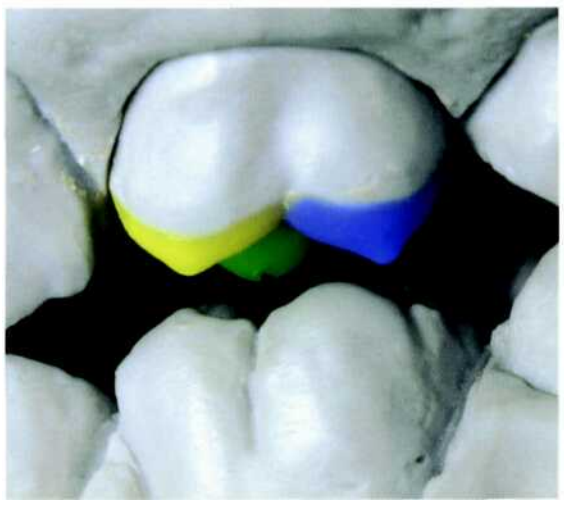
Right: Functional wax-up of the occlusal surface of an upper right first molar.

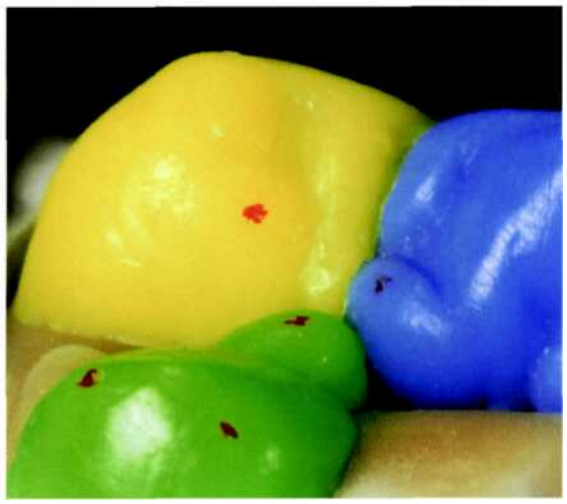


674 Functional chewing surfaces in the mandibular
Left: Intact natural lower molar and premolar. The functional paths of the mesiolingual cusp of the upper left first molar are represented by the colored lines as follows: black = protrusion; blue = laterotrusion; green = mediotrusion; red-green = retromediotrusion; red-blue = retrolaterotrusion.

Right: Functional wax-up of a lower left first molar following the color-coding suggested by Schultz (1992).

Collection of D. Schultz





675 Centric contacts and posterior disocclusion
Left: One essential aspect to be kept in mind while forming the functional chewing surfaces is to provide ample "approach and departure" clearance spaces for the opposing cusps. Whenever there is an anterior-protected or canine-protected occlusion, the posterior teeth must disocclude during excursive movements.

Right: Centric stops are produced by skillfully building up the individual occlusal segments.

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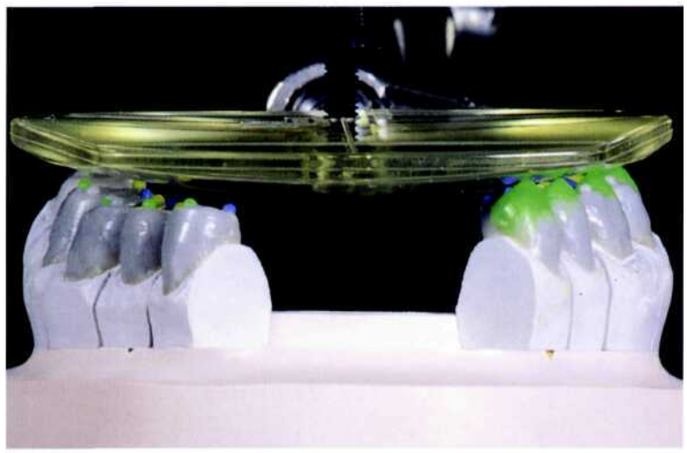
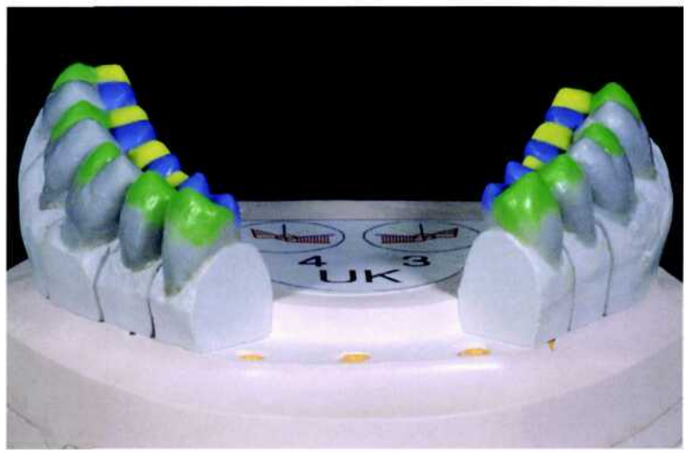
676 Diagnostic wax-up of the occlusal curves
In some cases a template can be helpful as an orientation guide for forming symmetrical sagittal and transverse compensating curves (here: Protar articulator by KaVo).

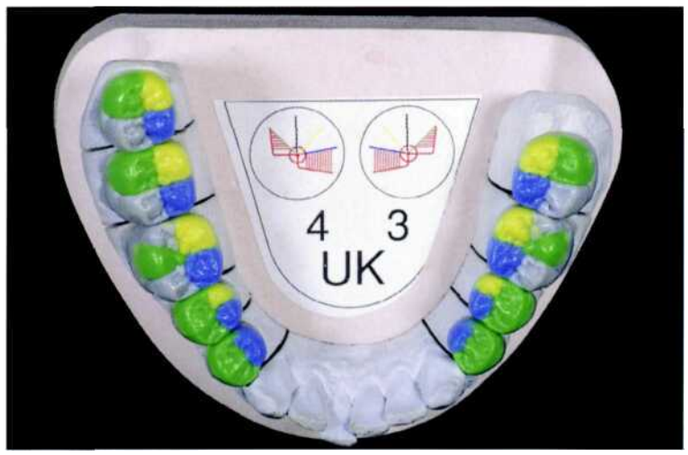
677 Forming the transverse compensating curve
The heights of the lingual and buccal cusps of the lower posterior teeth are built up until they contact the template.



678 Wax-up of the mandibular posterior teeth
The individual segments of the occlusal surfaces have been formed in color-coded wax according to the "natural wax-up technique" of Schulz.



679 Refinement of the mandibular posterior teeth
The occlusal surfaces of the molars and premolars have been anatomically refined while care was taken to preserve the simultaneous centric contacts and interference-free dynamic occlusion.
UK = lower jaw (quadrants 3 and 4)



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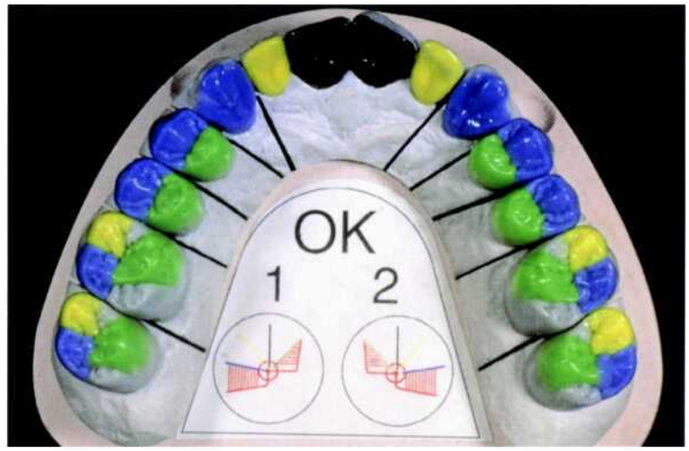
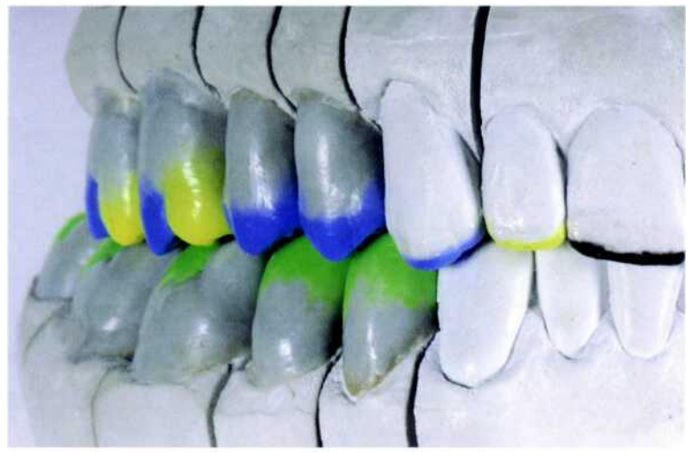


680 Completed wax-up of the maxillary teeth
The lingual surfaces of the upper incisors and canines are likewise refined to correct their guiding characteristics.
OK = upperjaw (quadrants 1 and 2).



681 Diagnostic wax-up in maximum occlusion
In maximum occlusion all posterior teeth make simultaneous contacts with equal force.

682 Canine guidance
In this case the diagnostic wax-up makes it apparent that an initial disocclusion of the posterior teeth can be achieved by a slight corrective addition to the lingual surfaces of the maxillary canines. The eccentric guiding contacts must under no circumstances be allowed to fall on the distal facets of the maxillary canines, however.

683 Posterior disocclusion
In protrusive mandibular movements also, an immediate anterior guidance provides interference-free disocclusion of all the other teeth.

Collection of D. Schulz
(Figs. 676-683)

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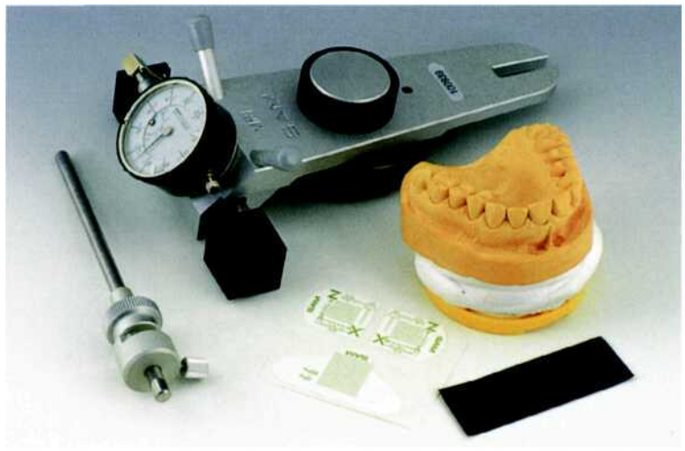
Condylar Position Analysis using Mounted Casts

Of special interest in the area of temporomandibular joint diagnosis is the determination of the spatial shift of the condyle from its physiological (= centric) or adapted starting position into the position forced upon it by maximum intercuspation of the teeth. Because even a change of as little as 0.5 mm in the position of the condyle can be accompanied by an improvement or worsening of the patient's symptoms (Lotzmann 1999), the jaw registration procedure selected for transferring the condylar position to an articulator should have the capacity for extensive three-dimensional analysis. The hinge axis registration has proven useful for measuring condylar displacements. This requires, of course, that the selected measuring points lie on the transverse hinge axis. The measuring points will exhibit movements analogous to the translation of the condyles, and so the measured shift of the hinge axis points, corrected for the intercondylar distance, can be interpreted as the shift of the condyles. Procedures that mark directly on the patient, such as paraocclusal axiography, offer the advantage that the relationship of the hinge axis position to both occlusion-guided and nonocclusion-guided hinge axis paths can be represented and compared directly (Jähnig et al. 1980, Slavicek 1981).

684 Mandibular position indicator (MPI)
The MPI (by SAM) consists of a modified upper member of a SAM Articulator. Sliding measuring cubes are placed on the mounting axis in place of the condylar housings.

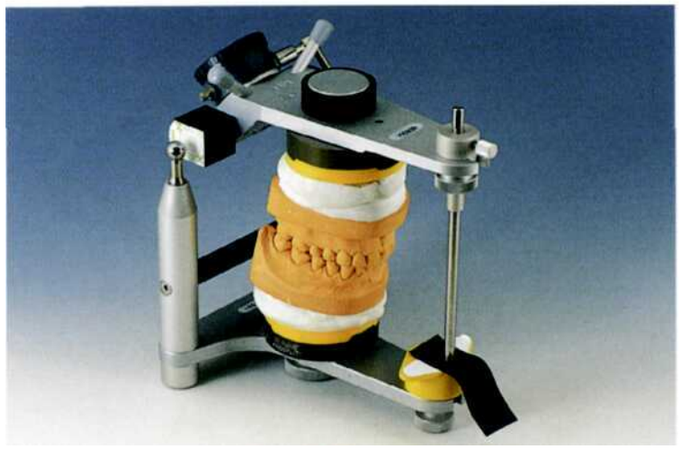


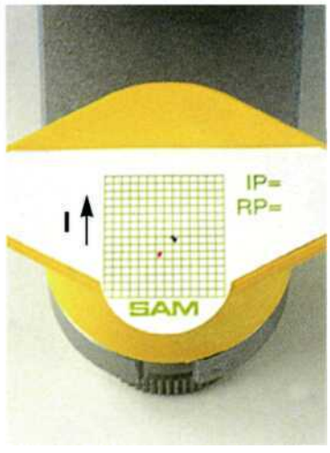
685 Marking the incisal pin position in centric
The casts are mounted in the correct relation to the cranium and joints. For a closed centric the upper member of the articulator is closed to the first occlusal contact and the position of the incisal pin is marked on the recording sticker with red articulating tape. The height of the incisal pin is entered as value h under RKP (retruded contact position).

Right: Marking of the incisal pin in centric (here RKP or RP).

686 Marking the incisal pin position at maximal intercuspation of the casts
Recording stickers are placed on the measuring cubes, and the maxillary cast is transferred to the MPI. The transverse axis of the MPI is now the same as the mounting axis of the articulator. The maxillary cast is placed into maximal occlusion (IOP), and the position of the incisal pin is marked on the incisal table with black tape.

Right: The height of the incisal pin is recorded under IP. "Delta I" is the difference between RP and IP in the sagittal plane.





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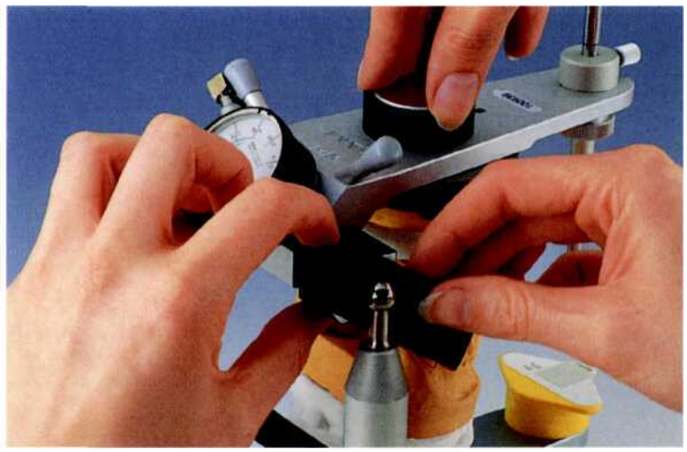
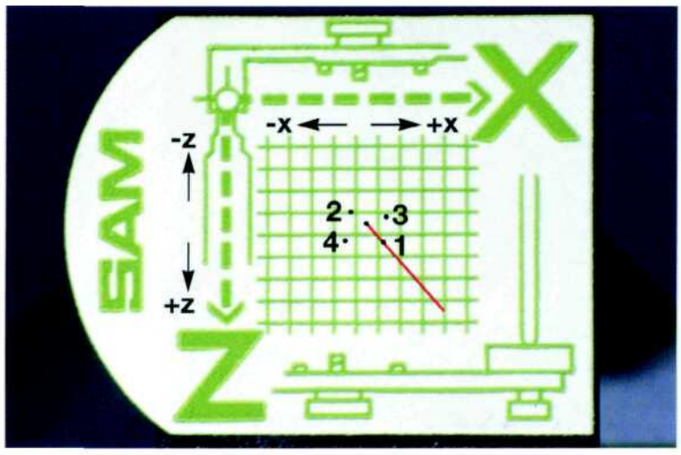
One definite disadvantage is that it is difficult to achieve an individual reproducible record of the shift of the axis. Indirect measurement of intermaxillary relations by using mounted casts was accomplished long ago by Thielemann (1939) with the Mirror Kinometer. The Mandibular Position Indicator (MPI; Mack 1980) is an instrument that attaches to the SAM articulator and registers the spatial shift of the mandible relative to defined measuring points on the hinge axis and on the incisal pin. Results can be read both graphically and on an analog dial.

When performing a condylar position analysis it is essential to recognize that its diagnostic relevance is largely dependent upon the quality of the centric occlusal record. For example, when there is a permanent superior, posterior, or posterosuperior displacement of the condyles with constriction of the capsules, the registered axis points may closely coincide with those determined by the occlusion and thereby mimic a stable centric occlusion. Furthermore, inaccuracies in the occlusal record, in the casts, and in locating the hinge axis can lead to a false diagnosis of a shift of the axis that actually does not exist.

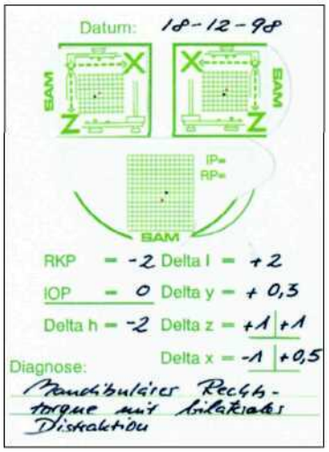


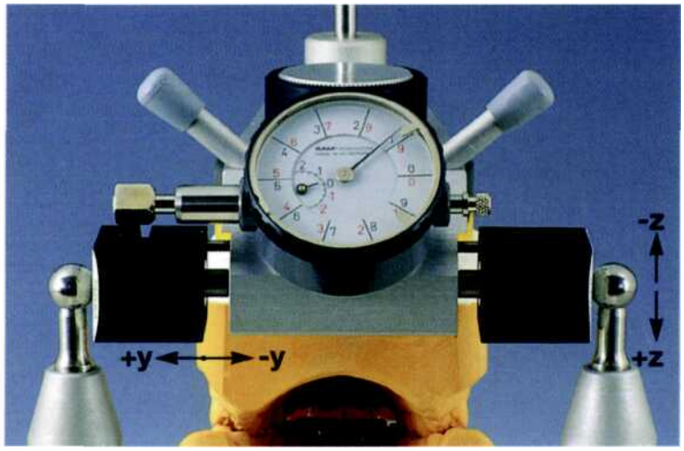
687 Marking the axis position in maximal cast intercuspation
While an assistant holds the MPI in maximal occlusion, each measuring cube is pulled out until it contacts black articulating tape held over the condylar ball. This marks the axis position dictated by the occlusion on the recording label.



688 Marking the axis position in centric
Initial condylar path drawn in red. Displacements of the axis in maximal occlusion: 1 anterior, 2 posterior, 3 superior, 4 inferior.

Left: As the measuring cubes are pushed in, the recording labels are perforated by pins from within. These perforations mark the axis position as determined by the centric occlusal record. A vertical shift of the axis is indicated as *z* and a horizontal shift as x. Displacements directed into the articulator space are always given a positive value.





689 Measuring the transverse shift
In a symmetrical arrangement the distance between measuring cube and articulator frame is 5 mm on both sides. If the space on the left is reduced this means that the mandible has shifted to the right in maximal occlusion. The distance is noted under delta = -y. A displacement to the left is recorded correspondingly as +y.

Left: Example for filling out the MPI results form.

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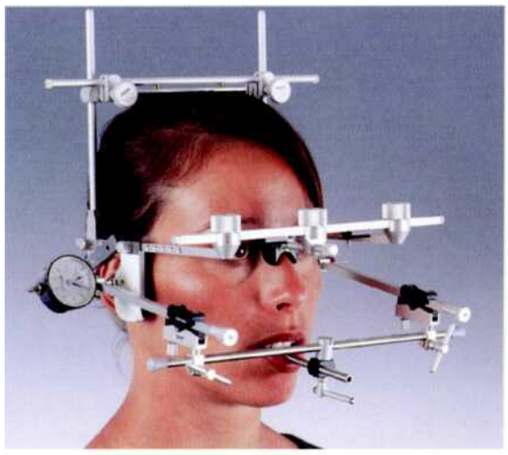
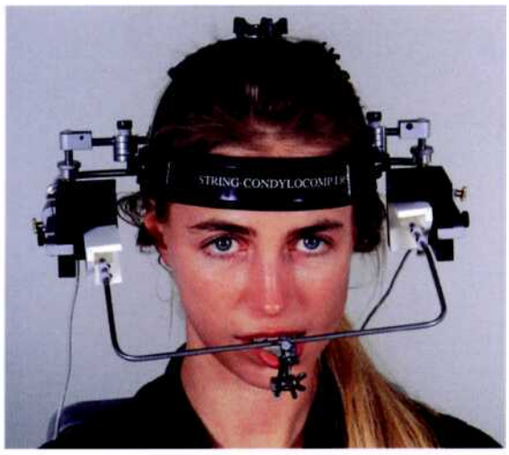
Instrumented Analysis of Jaw Movements

By the expression "instrumented analysis of jaw movements" is meant the dynamic tracing of mandibular movements and their diagnostic interpretation. According to our current understanding, this is a supplemental analytical element that provides limited information useful for complementing the patient history and manual functional analysis. Instrumented analysis of jaw movements is especially useful for:

- determining the joint values of the individual patient (curve and inclination of the condylar path, Bennett angle, course of the mediotrusive and laterotrusive tracks) for programming the joints of an articulator, and
- describing the paths of condylar movements during both active and manipulated mandibular movements, as well as for analyzing condylar displacements caused by the occlusion.





690 Mechanical and electronic recording systems
Left: SAM Axiograph for making direct mechanical tracings of hinge axis movements. This system can also be further modified to form an electronic recording system (e.g. Axiotron).

Right: The String Condylocomp LR3 for making computerized recordings of hinge axis movements with-

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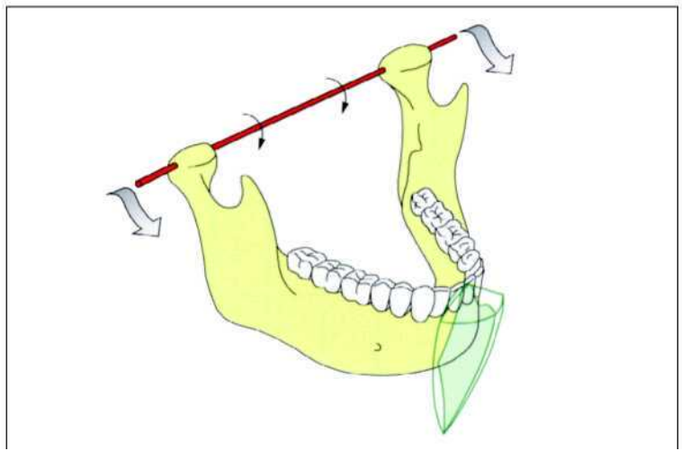
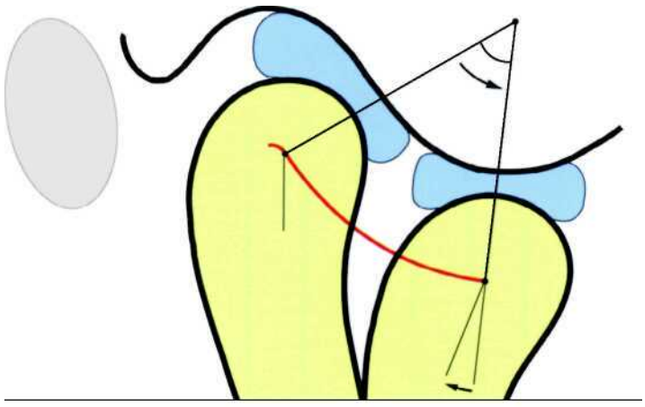
compare movement paths that were drawn both *with* and without tooth contact (Slavicek 1981).

This assumes, of course, that the registration system is mounted independently of the occlusion (Kubein et al. 1979, Janig et al. 1980, Slavicek 1981). The patient must be able to freely assume his static and dynamic occlusion and execute movements without interference from the recording apparatus. If the tooth-guided and non-tooth-guided paths of a defined movement (e.g. protrusion or mediotrusion) coincide, then the occlusion is exerting no clinically relevant forced guidance upon the temporomandibular joint. This can be considered evidence of occlusoarticular harmony. In addition, tracings of active and passive movements can be superimposed to complement the manual functional analysis.

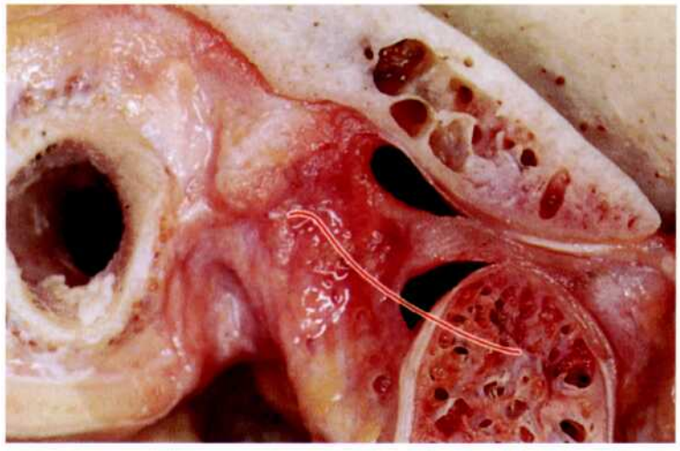
With the aid of instrumented analysis of movements, disturbances in the course of mandibular movements and occlusion-induced displacements of the condyles can be verified earlier and with higher resolution than would be possible through clinical manipulation. Important from the legal standpoint is the ability to document and store graphically or electronically each patient's movement patterns for later evaluation and comparison.



691 Transverse hinge axis of the mandible
The range of motion of any point on the mandible can be defined by the extent and coordination of rotation and translation of the transverse hinge axis (red).



692 Principle of movement of the condyle in the sagittal plane
The temporomandibular joint can be described not just as a rotating and sliding joint, but also as a doubly rotating joint.
One rotational movement of the condyles takes place around their functional transverse axis, while the other occurs as they orbit around a second axis located in the temporal bone (Kubein-Meesenburg 1985).



693 Anatomical preparation of a temporomandibular joint in protrusive condylar position
Macroscopic sagittal section of a human temporomandibular joint. The protrusive path of the hinge axis, represented by the red line, is largely determined by the radii of curvature of the contacting functional surfaces of the articular eminence, articular tubercle, and condyle.

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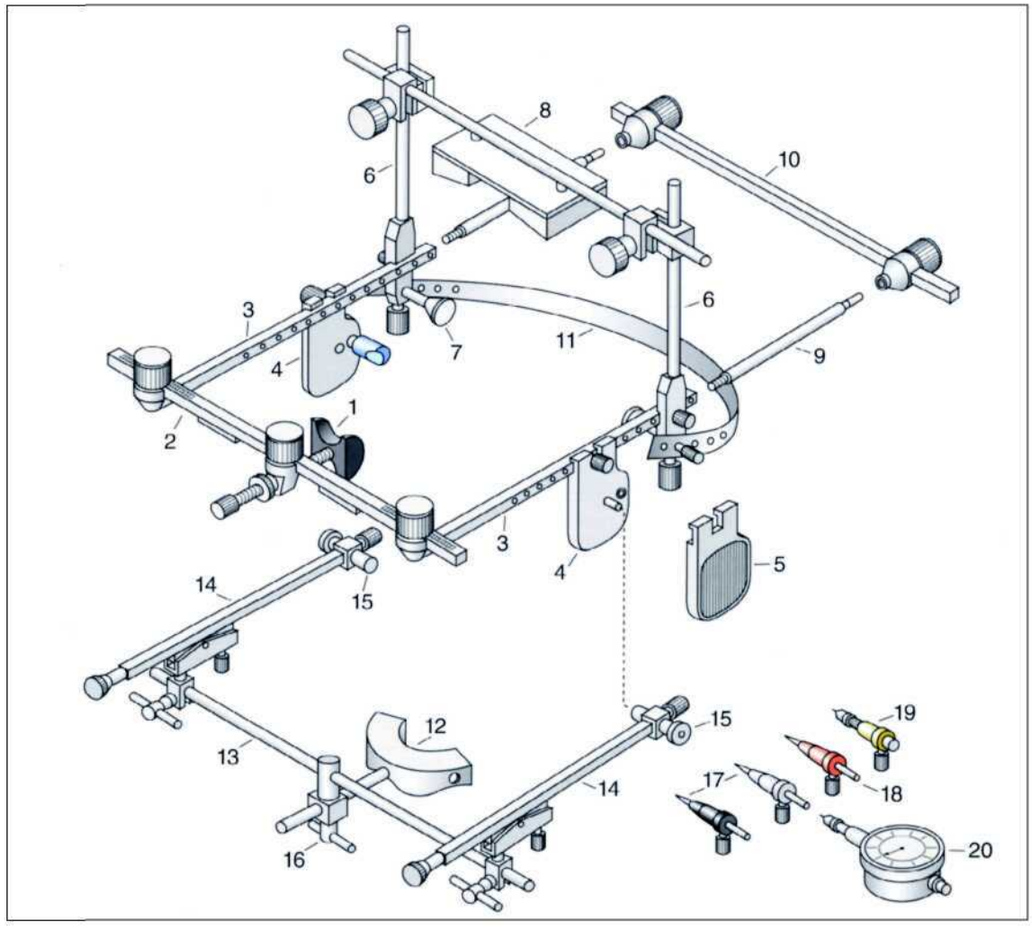
Mechanical Registration of the Hinge Axis Movements (Axiography)

The movement of any given point in the mandible can be defined by the magnitude and coordination of rotation and translation of the transverse hinge axis. The static and dynamic displacements of the mandible in the three dimensions of space must be recorded in their relation to defined measuring points on the hinge axis. Only in this way can the translatory movement of the mandible executed in combination with rotation be measured without paraxial distortion effects. In contrast to classic pantography, in which the mediotrusive and laterotrusive pathways were recorded on registration plates placed beside the axis, axiography permits spatial measurements of mandibular movements to be made from the hinge axis (Mack 1979, 1980). The tracings of movements are called axiograms. Axiography, with its mechanical tracings, serves primarily to gather data on the individual patient's joints in preparation for programming the joints on the articulator. Usually, protrusive axiographic tracings are adequate for evaluation of the curvature and inclination of the sagittal condylar path. Measurement of the medial displacement of the mandible that accompanies

694 Schematic drawing of the SAM Axiograph, Type III

Flag bow
1 Nasion relator
2 Anterior rod
3 Upper sidearm
4 Alignment flag with ear piece and alignment pin
5 Recording flag
6 Mastoid and vertex support rod assembly
7 Mastoid support
8 Vertex support
9 Flag sidearm extension rod
10 Posterior crossbar (reference alignment gauge)
11 Elastic neckband

Recording bow
12 Tray clutch
13 Anterior rod of the recording bow
14 Sidearm of the recording bow
15 Alignment tube
16 Universal clamp for anterior rod
17 Hinge axis locating styluses
18 Hinge axis marking stylus
19 Recording assembly with lead holder
20 Dial gauge with lead holder



695 Placing the flag bow
After loosening the thumbscrews, the side-arms are pushed medially until the ear pieces of the alignment flags are securely placed in the orifices of the ears.

Right Placement of the ear pieces and the lateral alignment pins has defined an arbitrary hinge axis.

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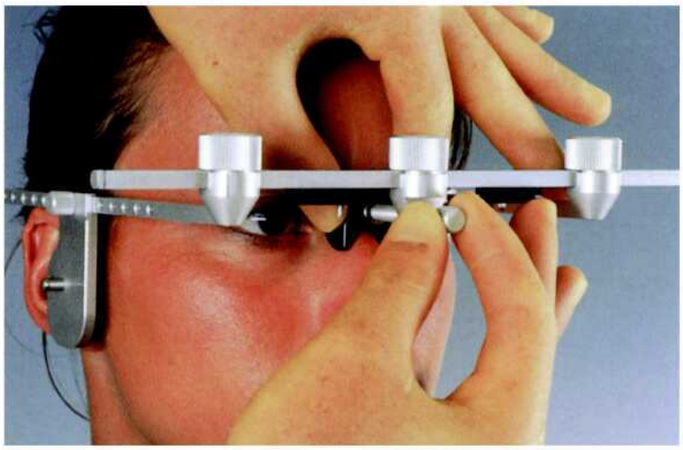
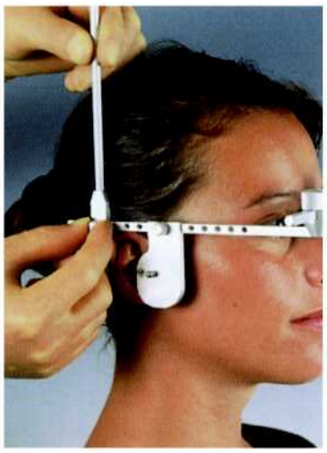
lateral movements serves to determine the Bennett angle and the basic form of the Bennett movement of the mediotruding condyle (e.g. immediate side shift). The clinician should be able to find these same mediotrusive paths through additional manipulation. Only in this way can one document the condylar border movements that may be experienced by the patient during parafunctional activity.

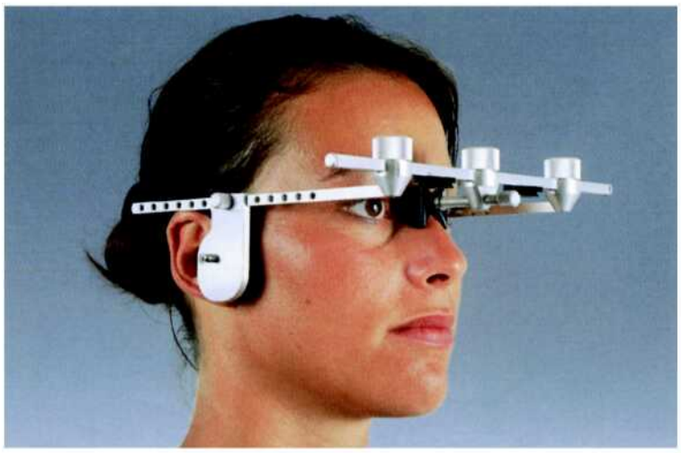
For tracing the movements relevant to the programming of the articulator it is usually adequate to use a tray clutch, which is closed on its occlusal surface, to attach the mandibular recording bow to the lower dental arch. This of course precludes registration of tooth-guided mandibular movements. If axiography is to also provide information on the influence of the occlusion upon the dynamic function of the temporomandibular joints, however, then the mandibular registration bow must be fixed to the buccal and labial surfaces of the lower teeth with a special adapter that leaves the occlusal surfaces free (Slavicek 1981).



696 Adapting the nasion relator
The nasion relator is adjusted by means of the anterior thumbscrew clamp until the flag bow is held against the head.

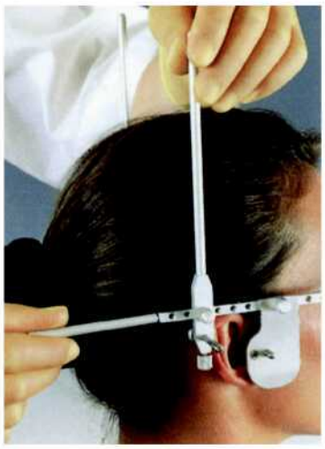
Left If necessary, the nasion relator can be prefitted with a little silicone putty.

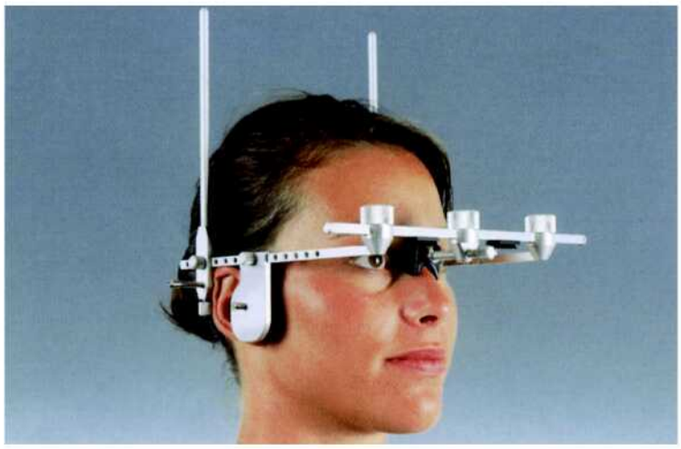




697 Attaching the vertical bars
The alignment of the flag bow to the skull is determined by the ear pieces and the nasion relator.

Left: Attaching the vertical rods for the mastoid and vertex supports.





698 Attaching the sidearm extension rod
The flag bow is fitted with a vertical rod on each side.

Left: The extension rods are screwed onto the side-arms.

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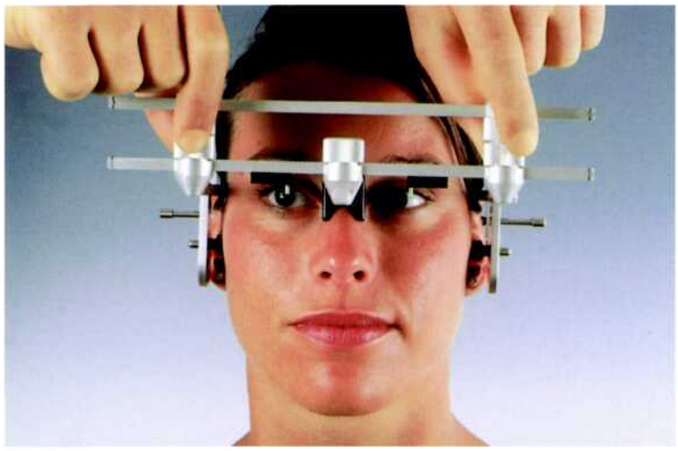
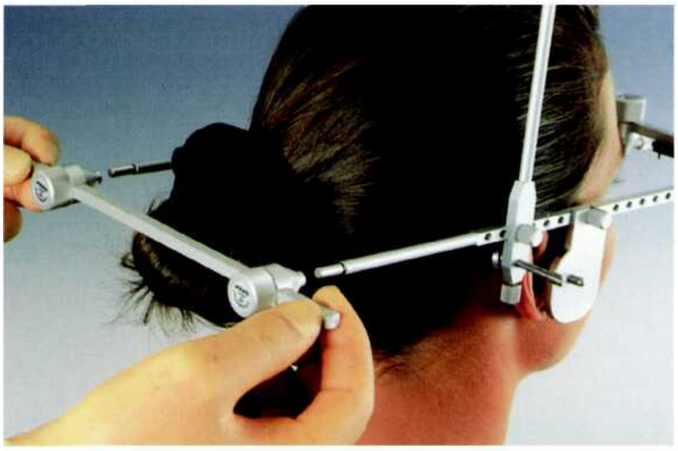
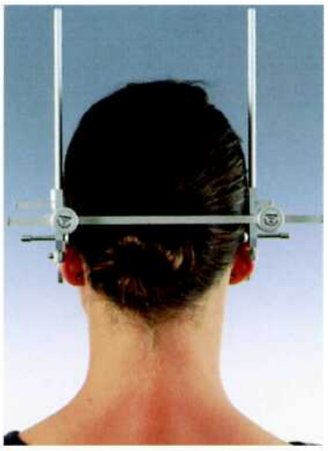
699 Adjusting the posterior crossbar
The distance between the fixation screws of the posterior crossbar (= reference alignment gauge) is adjusted so that it is the same as that between the fixation screws on the anterior bar.



700 Attaching the posterior crossbar
The previously adjusted posterior bar is slipped passively over the extension rods.

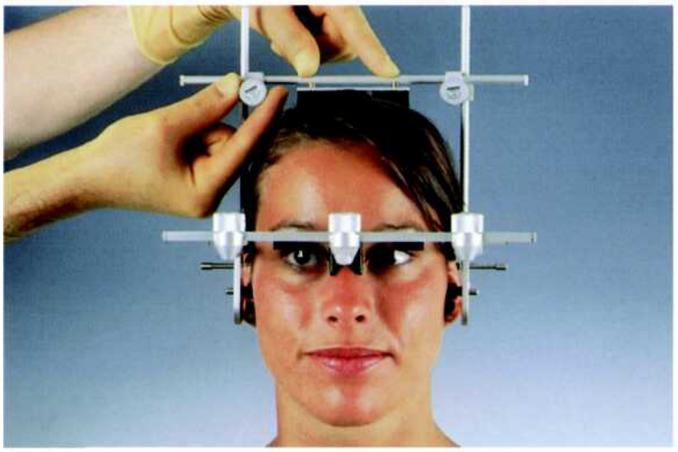
Right The posterior crossbar further increases the rigidity of the flag bow.

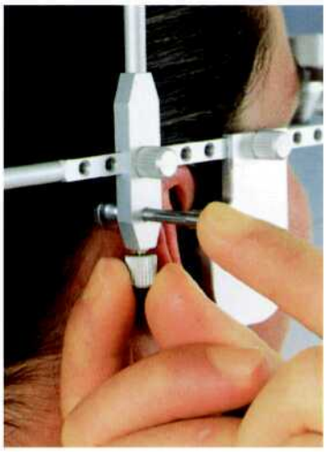




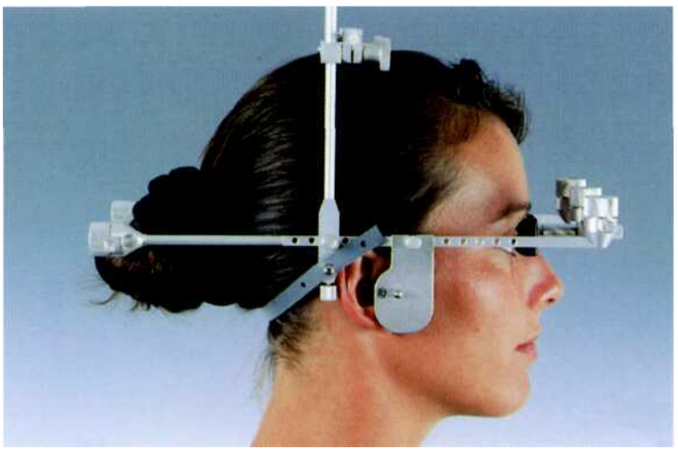
701 Placement of the vertex and mastoid supports
The screw clamps of the vertex support are slipped over the vertical rods and, using light pressure, attached by tightening the thumbscrews.

Right: Finally the lateral mastoid supports are brought into flat contact with the skin and fixed in this position.





702 The assembled flag bow in place
The elastic band that is lightly stretched from one mastoid support to the other at the hairline gives the flag bow additional stability. The vertex and mastoid supports provide transverse stability to the flag bow so that now the posterior crossbar and the flag side-arm extension rods can be removed.



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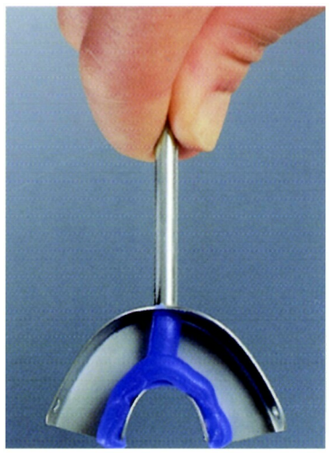
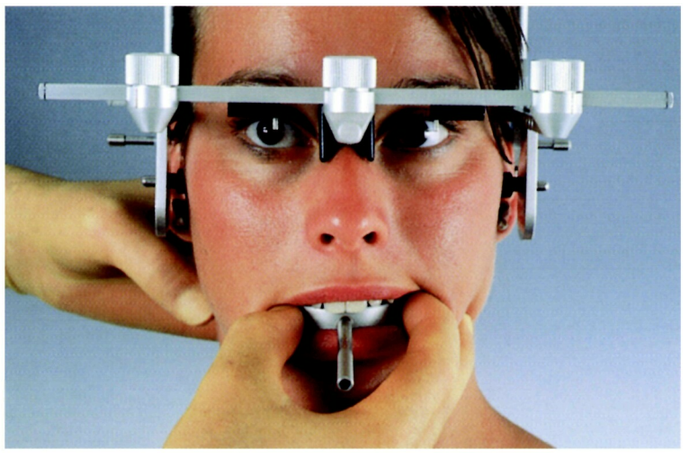
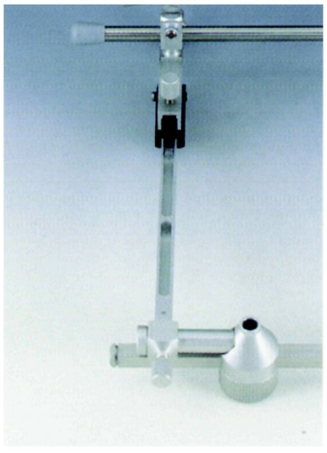
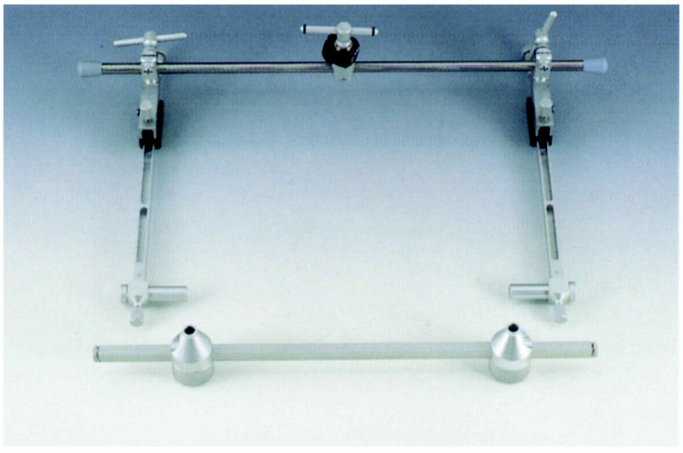




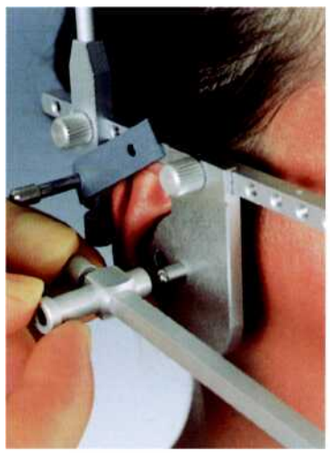
703 Insertion of the tray clutch
Soft wax strips are placed inside the tray at the midline and along the lingual flange to serve as intentional fracture lines during removal of the tray after it is filled with impression plaster.

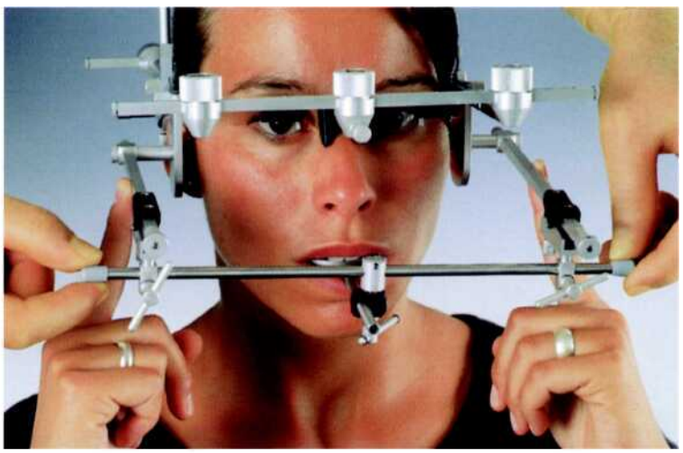
Right: To minimize interference with the occlusion, the tray clutch filled with impression plaster is aligned with the midline and seated until it rests against the chewing surfaces. The patient then closes against the tray in the retruded mandibular position until the plaster has hardened.





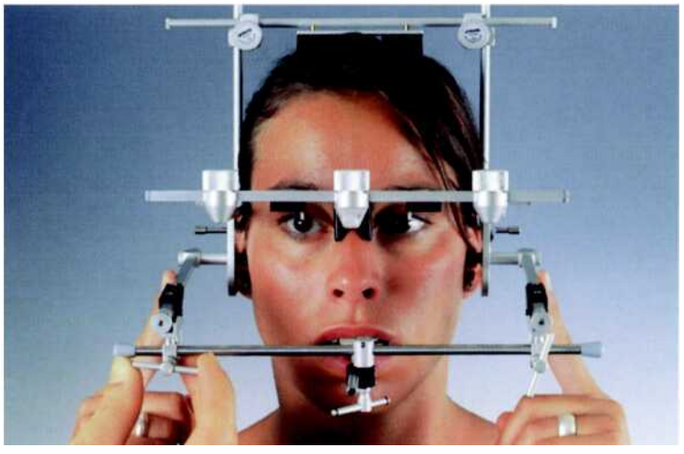
704 Preparation of the mandibular recording bow
Both side-arms are set in their sagittal planes at the zero mark and the vertical adjustment screws are brought to their middle positions. The alignment tubes are attached to the side-arms, and the side-arms are made parallel with one another. *Left:* The side-arms are positioned on the anterior cross rod (near top of photograph) so that the alignment tubes rest securely, but without strain, in the seats milled into the sides of the thumbscrew clamps of the posterior crossbar. The posterior crossbar has been previously adjusted on the patient.





705 Placement of the recording bow
The T-handle clamp connected to the center of the anterior rod is slid over the sagittal rod of the tray clutch. The side-arms are connected to the flag bow by the alignment tubes. Any mechanical stress is relieved by gentle rotation of the anterior rod.

Left: The alignment tubes are slid medially until they contact the alignment pins of the flag bow.



706 Fixation of the recording bow
While the side-arms are held so that the alignment tubes are in stable contact with the alignment flags, the recording bow is fixed to the posteriorly positioned mandible by tightening the clamps and thumbscrews.

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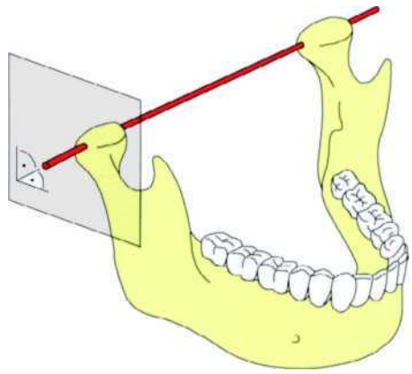
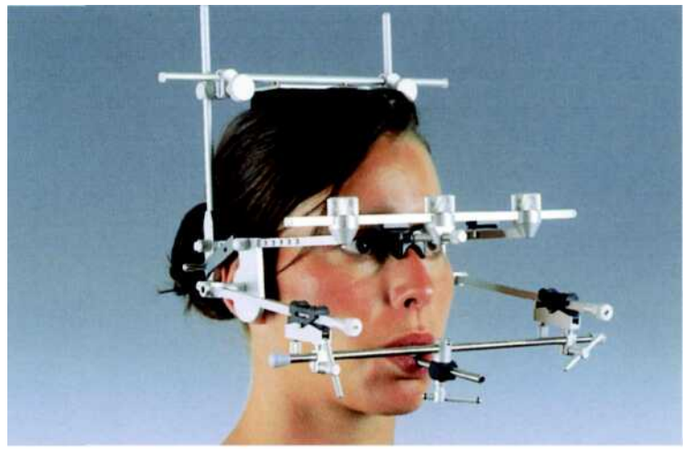
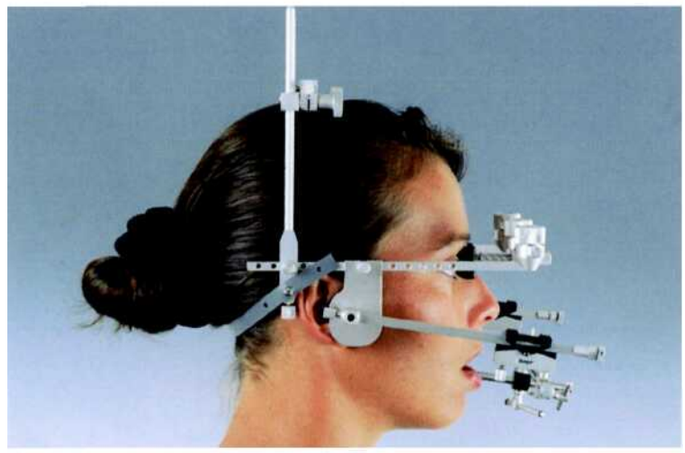
707 Ideal orientation of the recording surfaces to the tracing axis
An essential precondition for an artifact-free tracing of the hinge axis movements is that the recording surfaces be positioned perpendicular to the hinge axis in centric jaw relation (Lotzmann 1990b).



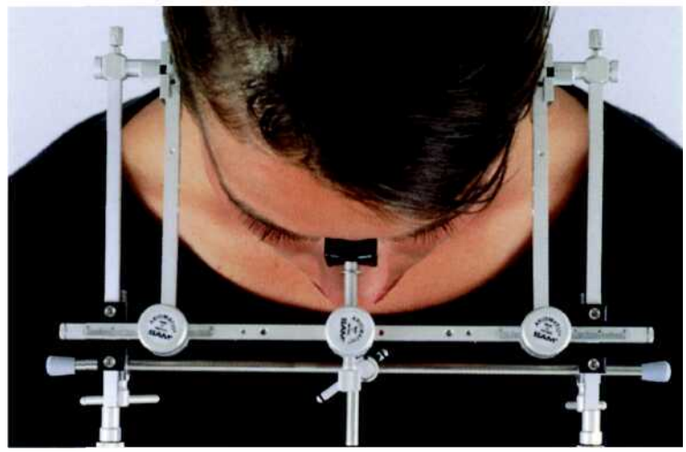
708 Principle of coaxial mounting
The principle of coaxial mounting of the Axiograph III automatically leads to correct orientation of the recording bow to the flag bow.



709 Lateral view of the flag bow and recording bow
The arbitrary hinge axis passes through the recording surfaces at right angles.



710 Top view of the flag bow and recording bow
In the horizontal plane, too, the arbitrary hinge axis is perpendicular to the recording surfaces. The distance between the two recording surfaces, necessary for later evaluation of the paths of movements, is measured and recorded.



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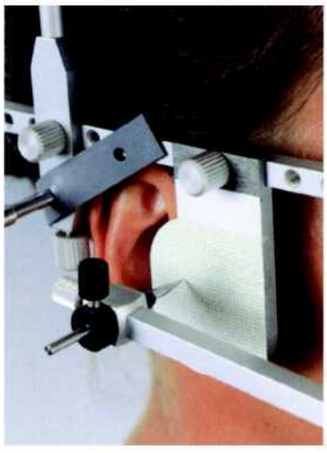
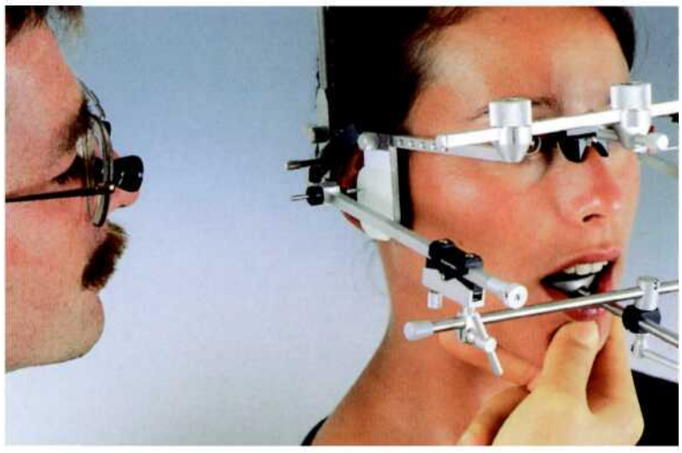
711 Attachment of the recording flags
Left: After removal of the two small alignment tubes, the alignment flags are removed from both sidearms.

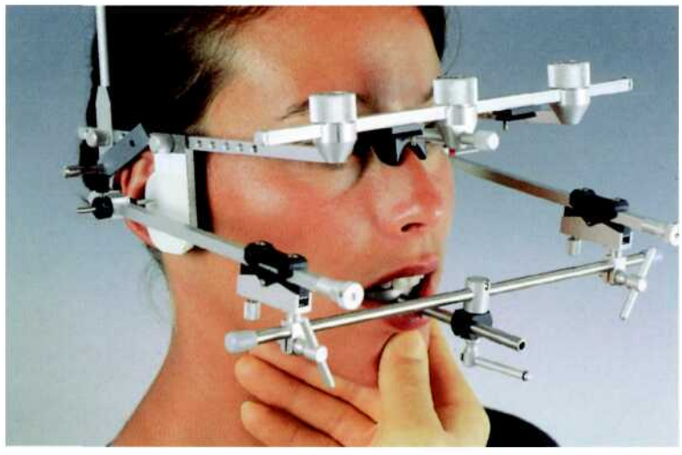
Right: The recording plates, covered by adhesive-backed graph paper, are attached to the flag bow through the same threaded holes that were used for the alignment flags.



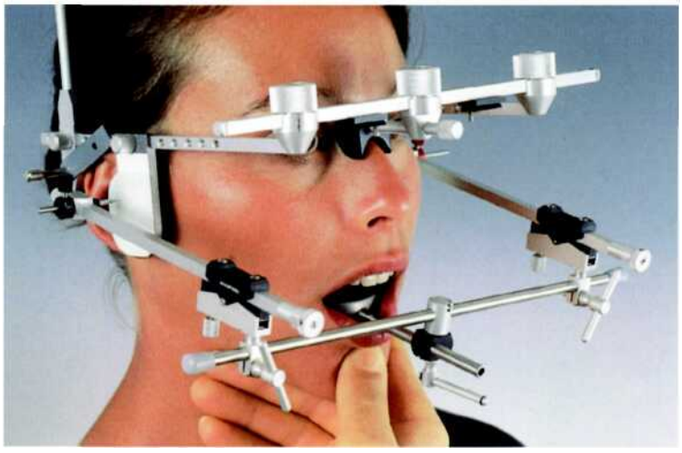


712 Location of the hinge axis
Location of the hinge axis should be performed under cautious manual guidance of the mandible to minimize translational movements. (Movements are monitored with magnifying loupes!)

Left: The hinge axis locating stylus with a black or silver-colored collar is slid into the sidearm of the recording bow and fixed in place.



713 Avoidance of tooth contact against the tray clutch
The clinician carefully guides the patient's lower jaw posteriorly with the thumb as the index and middle fingers give support near the angles of the jaw in an anterosuperior direction. The patient should hold the mouth nearly closed, but must avoid contacting the tray with the teeth.



714 Relaxed opening of the jaws without translation
The patient opens the mouth approximately 12 mm with as continuous a movement as possible. Excessive jaw opening will lead to a pronounced forward bodily movement of the mandible, while insufficient opening will make the precision of the axis location appear greater than it actually is.

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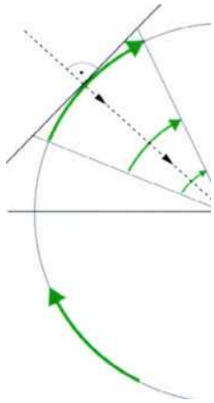
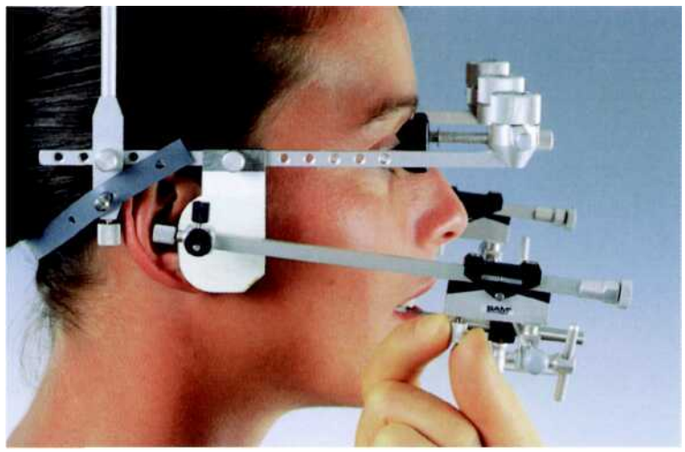
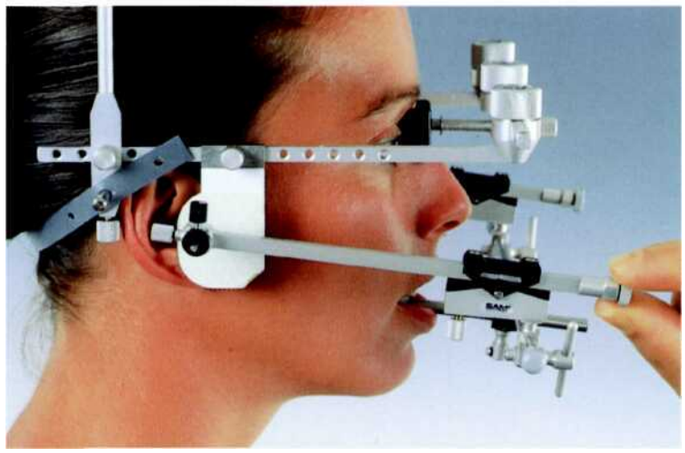
715 Principle for correcting the location of the hinge axis locating stylus
The direction and magnitude of movement of the hinge axis locating stylus allow one to close in on the position of the imaginary axis (S). During the procedure the movements are paused and the position of the stylus is corrected as necessary (Bosman 1974).



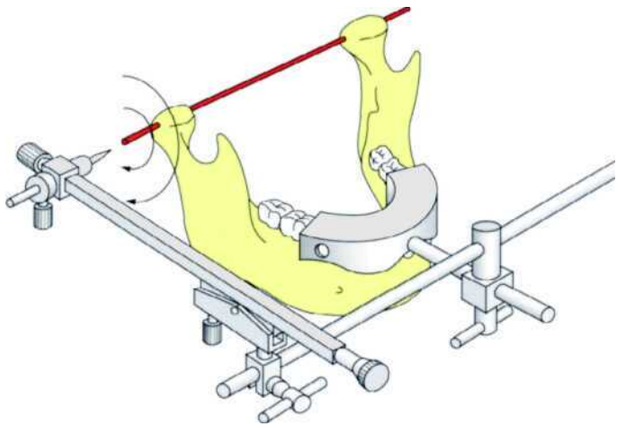
716 Vertical correction of the hinge axis locating stylus
By turning the knurled screw for tilting the side-arm vertically, the point of the locating stylus can be moved up or down to bring it nearer to the imaginary hinge axis.



717 Horizontal adjustment of the locating stylus
The knurled screw for moving the sidearm horizontally serves similarly to adjust the anterior-posterior position of the locating stylus.



718 Locating the individual hinge axis
Once the tip of the locating stylus no longer travels in a visible arc as the patient makes opening and closing movements (approximately 12 mm amplitude), it is lying on or in close proximity to the hinge axis of the mandible.



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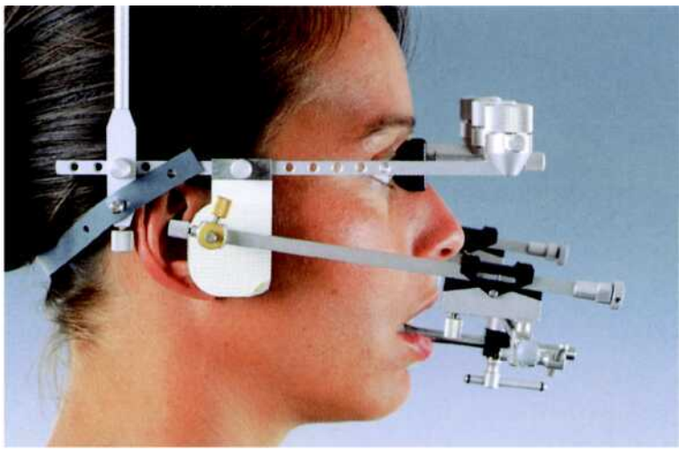
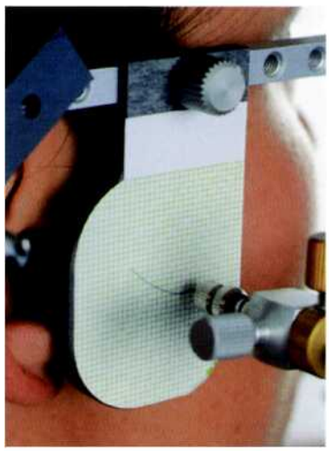
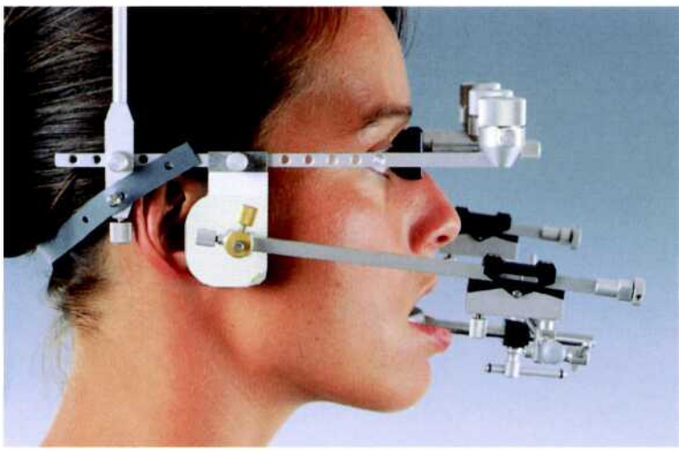


719 Tracing the protrusive movement
Lateral view at the starting point with the mandible in centric.

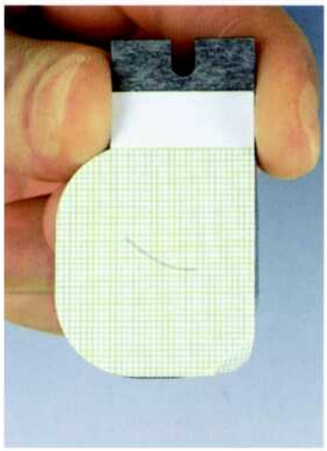
Left: The hinge axis locating stylus is replaced by the tracing attachment with the yellow collar. The mandible is now guided into centric, and the assistant places the spring-loaded black pencil lead against the recording flag.

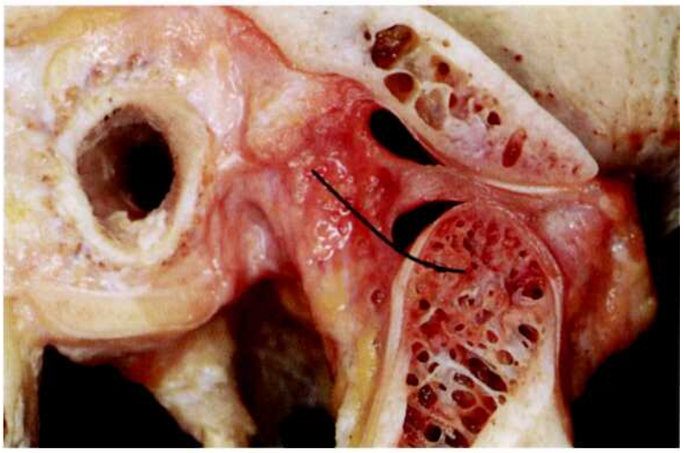




720 Maximal protrusion
Lateral view at maximal protrusive position.

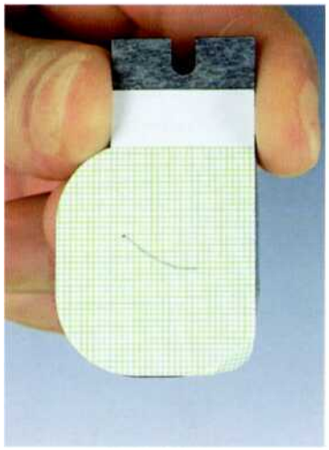
Left During the protrusive movement, the pencil lead traces the protrusive path of the hinge axis.

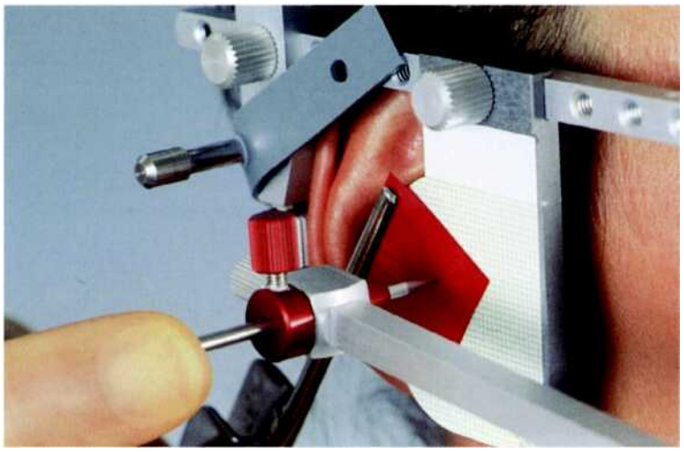




721 Normal joint function
Sagittal section of a human temporomandibular joint. The path of the axis drawn on the label corresponds closely to the functional joint surface of the temporal bone seen in the enlarged photograph.

Left: This hinge axis tracing, normal in length and curvature, is evidence of undisturbed joint function.





722 Marking the centric hinge axis point
To mark the centric hinge axis point, the yellow tracing assembly is replaced by the red attachment containing the flat-tipped axis marking stylus. The mandible is guided into centric, and the position of the hinge axis is marked on the recording label with red articulating film.

Left: Tracing of the protrusive path with the centric axis point marked in red.

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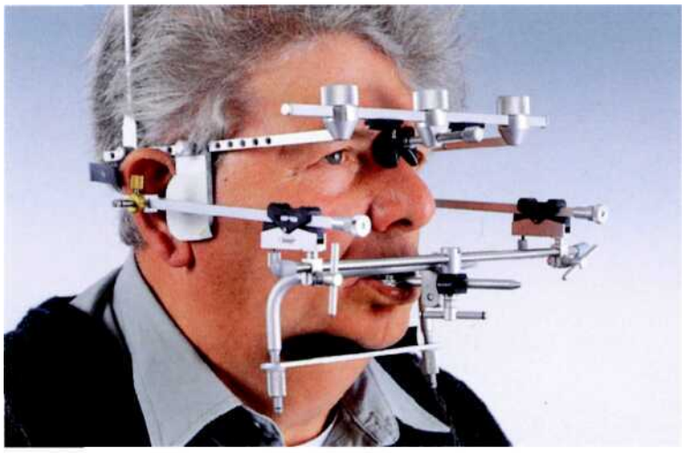
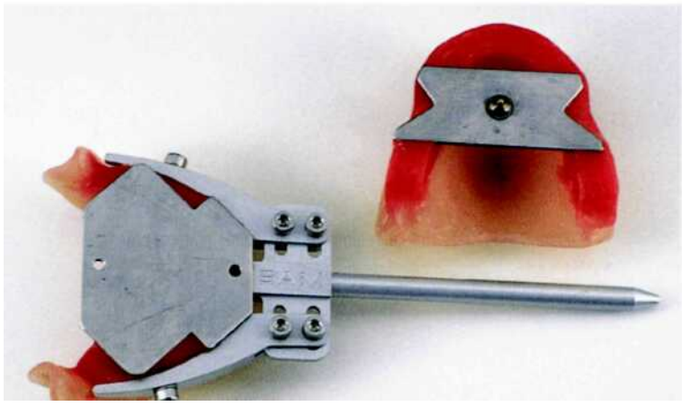
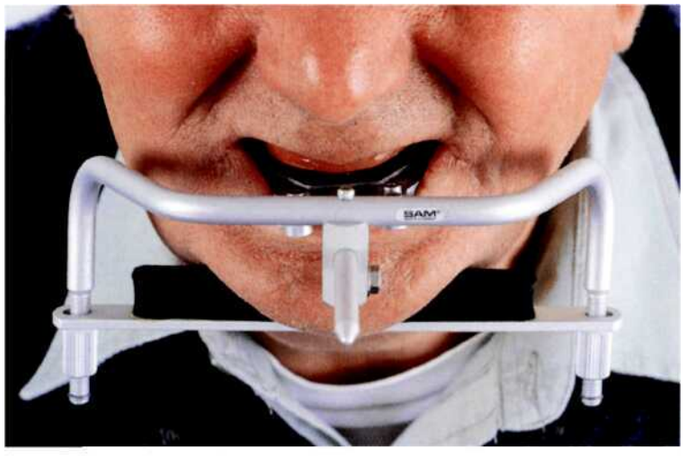
723 Mounting the axiograph on edentulous patients
In cases in which the alveolar ridge is still well formed, it is possible to attach the recording bow to the edentulous lower jaw with sufficient stability by using the special mandibular clamp (AXO 350, SAM).



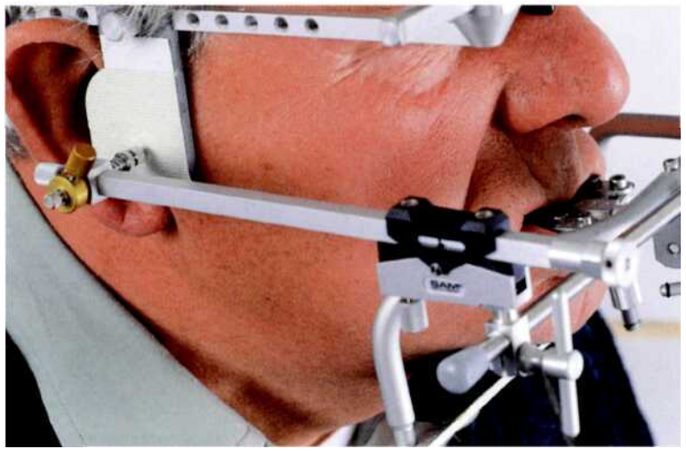
724 Intraoral central bearing pin and recording adapter
To impart adequate positional stability to the mandibular record base during the registration procedure it is recommended that an intraoral central bearing pin and plate system be used (here: Gerber-Set). The registration adapter (Axiodapt, SAM) is adapted to the facial surface of the lower wax rim and anchored into the resin record base by means of the side screws.



725 Mandibular clamp in place
The mandibular clamp is connected to the registration adapter. It presses against the inferior border of the mandible on both sides and thereby stabilizes the position of the mandibular record base.



726 Recording of the protrusive hinge axis path
The recording bow is attached to the registration adapter, as described above. The spring-loaded pencil lead traces the sagittal hinge axis path on the recording flag as the patient executes a protrusive movement with the central bearing pin sliding over the central bearing plate.



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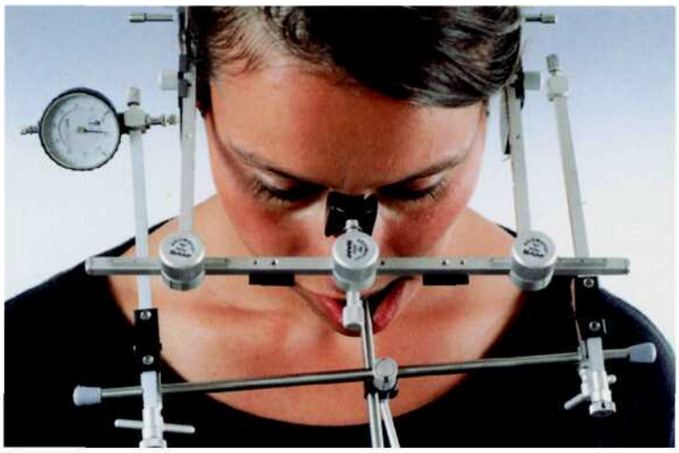
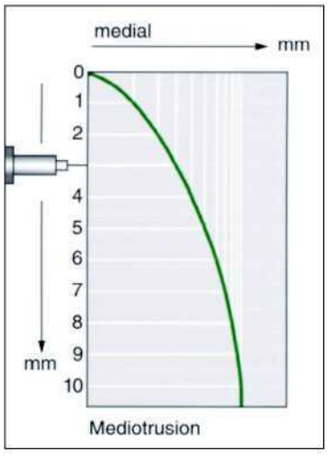
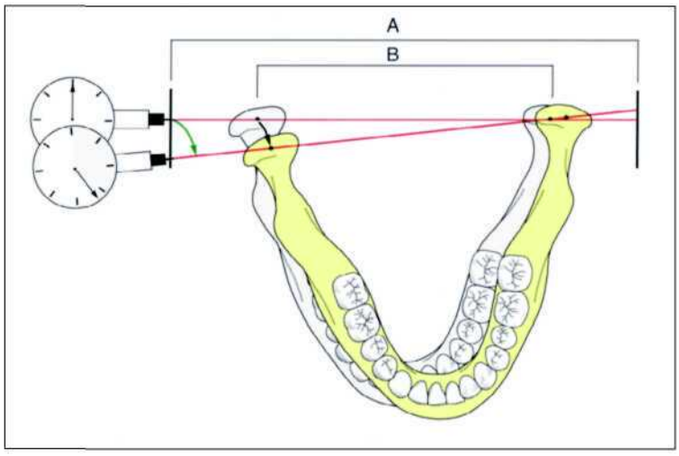


727 Recording the mediotrusive hinge axis path
To record the mediotrusive hinge axis path (Bennett angle, "side shift") the patient performs a laterotrusive movement to the opposite side.

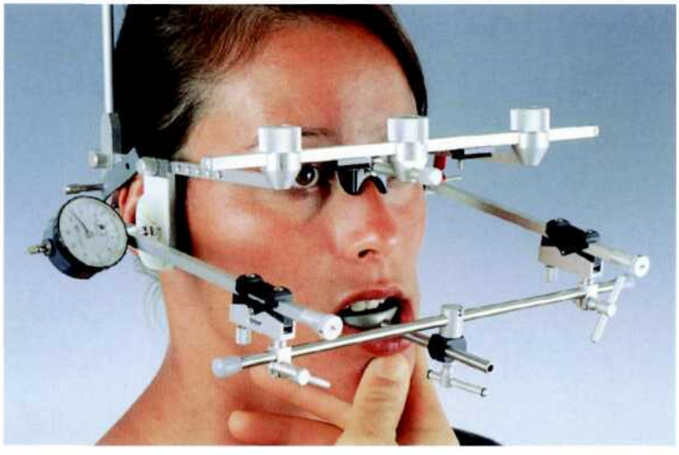
Left: In the mechanical version of the axiograph an analog dial displays the magnitude of the medial movement of the condyle.





728 Principle of geometric measurement of the mediotrusive path
The magnitude of the condyle's medial shift can be calculated from the analogous displacement of the hinge axis point against the recording flag. If the distance between the flags (A) and the intercondylar distance (**B**) are known, the actual movement of the condyle can be calculated.

Left The individual mediotrusive path can be constructed from the incrementally measured values, as will be explained in the following figures.



729 Guided mediotrusion
The recording assembly with pencil lead has been replaced by the dial gauge with lead holder. Starting in centric position, the patient's jaw is carefully guided in a slow mediotrusive movement.

Left: With attention to the starting point, the resulting tracing is covered by a transparent, adhesive-backed millimeter grid.

730 Incremental determination of the medial shift with the aid of the dial gauge
Left: The patient is guided into centric. The dial gauge is read at this starting point and the value entered in the axiograph record book (see p. 260).

Center: Medial shift at 5 mm of mediotrusion.

Right: Medial shift at 8 mm of mediotrusion.

Readings of the medial shift must be made at intervals of at least 1, 2, 5, and 10 mm of mediotrusion.

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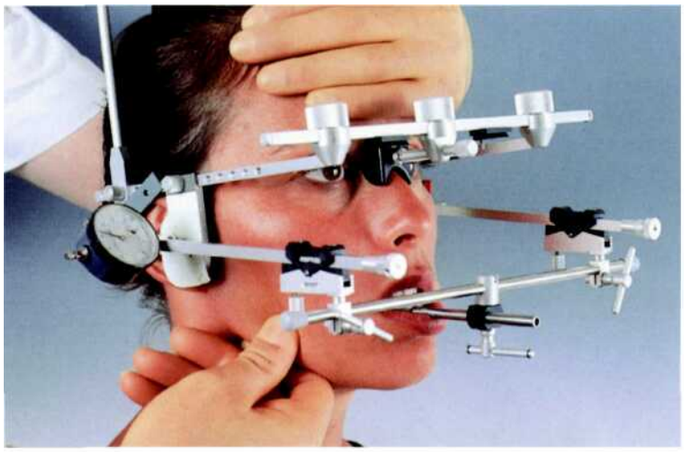
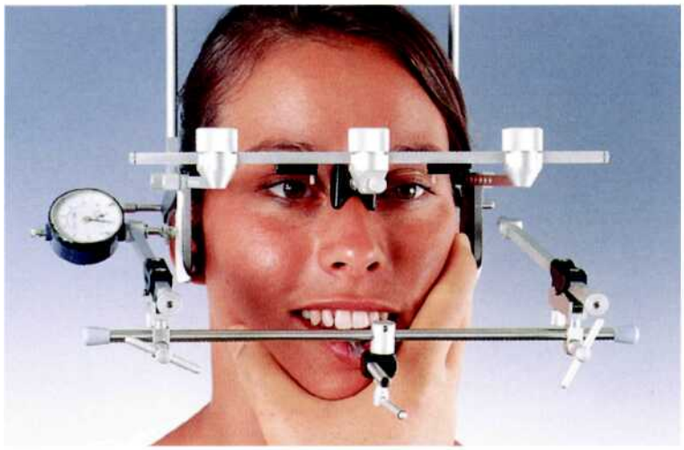
731 Induced mediotrusion I

To determine the medial border movements of the condyle, it is recommended that registration of the mediotrusive path also be carried out under manipulation. One of the dentist's hands exerts a controlled, medially directed force over the angle of the jaw, while the other hand braces the head.



732 Induced mediotrusion II

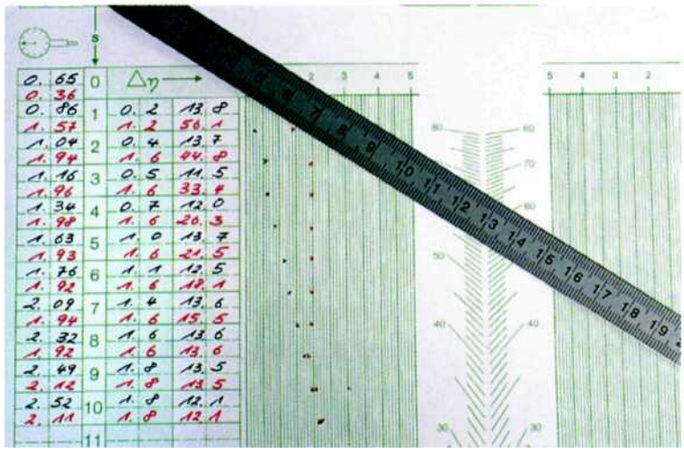
In this grasping technique for manipulating a mediotrusion, the index and middle fingers rest on the zygomatic arch on the opposite side while the thumb exerts a medially directed force on the angle of the jaw.



733 Record of the measured values and the graphic conversion

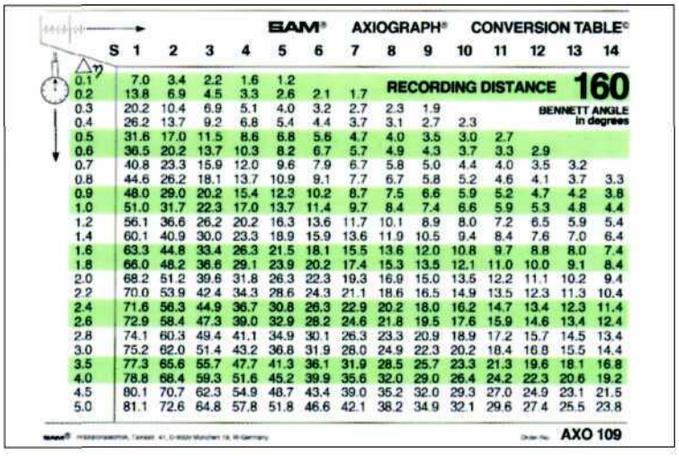
Each individual measurement is subtracted from the starting measurement. Black: measurements of an unguided mediotrusion. Red: measurements from a manipulated mediotrusion.

Each of these values is converted to an angular value and plotted graphically by using the conversion table (Fig. 734) and factoring in the distance between the flags.



734 Conversion table

The section of a conversion table for an inter-flag distance of 160 mm is shown here. This allows the measurements of the medial shift of the condyle made outside the joint to be corrected to the intercondylar distance of the articulator and converted to degrees of angle.



BAM® AXIOGRAPH® CONVERSION TABLE©

RECORDING DISTANCE 160

BENNETT ANGLE in degrees

S	1	2	3	4	5	6	7	8	9	10	11	12	13	14
0.1	7.0	3.4	2.2	1.6	1.2									
0.2	13.8	6.9	4.5	3.3	2.6	2.1	1.7							
0.3	20.2	10.4	6.9	5.1	4.0	3.2	2.7	2.3	1.9					
0.4	26.2	13.7	9.2	6.8	5.4	4.4	3.7	3.1	2.7	2.3				
0.5	31.6	17.0	11.5	8.6	6.8	5.6	4.7	4.0	3.5	3.0	2.7			
0.6	36.5	20.2	13.7	10.3	8.2	6.7	5.7	4.9	4.3	3.7	3.3	2.9		
0.7	40.8	23.3	15.9	12.0	9.6	7.9	6.7	5.8	5.0	4.4	4.0	3.5	3.2	
0.8	44.6	26.2	18.1	13.7	10.9	9.1	7.7	6.7	5.8	5.2	4.6	4.1	3.7	3.3
0.9	48.0	29.0	20.2	15.4	12.3	10.2	8.7	7.5	6.6	5.9	5.2	4.7	4.2	3.8
1.0	51.0	31.7	22.3	17.0	13.7	11.4	9.7	8.4	7.4	6.6	5.9	5.3	4.8	4.4
1.2	56.1	36.6	26.2	20.2	16.3	13.6	11.7	10.1	8.9	8.0	7.2	6.5	5.9	5.4
1.4	60.1	40.9	30.0	23.3	18.9	15.9	13.6	11.9	10.5	9.4	8.4	7.6	7.0	6.4
1.6	63.3	44.8	33.4	26.3	21.5	18.1	15.5	13.6	12.0	10.8	9.7	8.8	8.0	7.4
1.8	66.0	48.2	36.6	29.1	23.9	20.2	17.4	15.3	13.5	12.1	11.0	10.0	9.1	8.4
2.0	68.2	51.2	39.6	31.8	26.3	22.3	19.3	16.9	15.0	13.5	12.2	11.1	10.2	9.4
2.2	70.0	53.9	42.4	34.3	28.6	24.3	21.1	18.6	16.5	14.9	13.5	12.3	11.3	10.4
2.4	71.6	56.3	44.9	36.7	30.8	26.3	22.9	20.2	18.0	16.2	14.7	13.4	12.3	11.4
2.6	72.9	58.4	47.3	39.0	32.9	28.2	24.6	21.8	19.5	17.6	15.9	14.6	13.4	12.4
2.8	74.1	60.3	49.4	41.1	34.9	30.1	26.3	23.3	20.9	18.9	17.2	15.7	14.5	13.4
3.0	75.2	62.0	51.4	43.2	36.8	31.9	28.0	24.9	22.3	20.2	18.4	16.8	15.5	14.4
3.5	77.3	65.6	55.7	47.7	41.3	36.1	31.9	28.5	25.7	23.3	21.3	19.6	18.1	16.8
4.0	78.8	68.4	59.3	51.6	45.2	39.9	35.6	32.0	29.0	26.4	24.2	22.3	20.6	19.2
4.5	80.1	70.7	62.3	54.9	48.7	43.4	39.0	35.2	32.0	29.3	27.0	24.9	23.1	21.5
5.0	81.1	72.6	64.8	57.8	51.8	46.6	42.1	38.2	34.9	32.1	29.6	27.4	25.5	23.8

AXO 109

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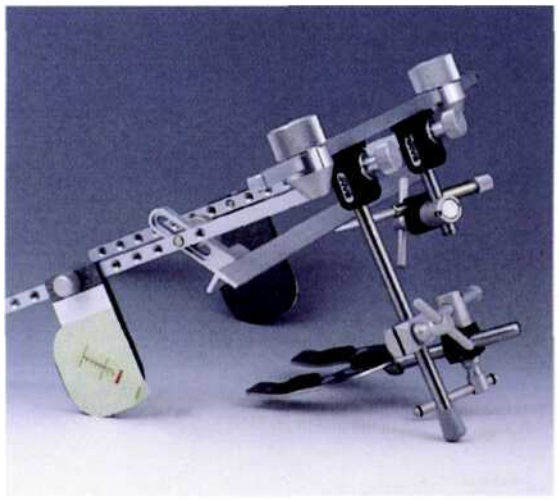
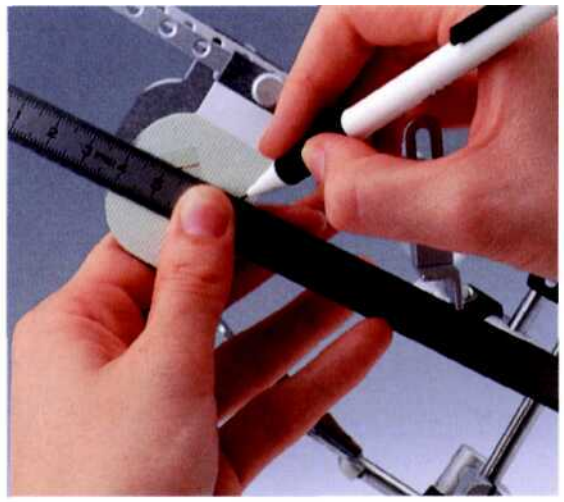
Evaluating the Axiograms and Programming the Articulator

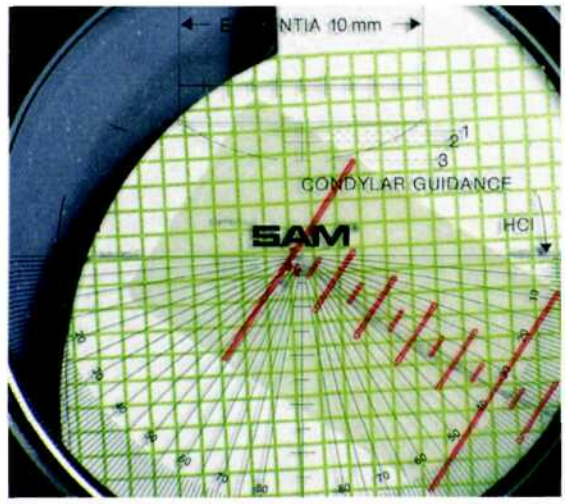
Articular factors have no meaning in the fabrication of occlusal splints with initial anterior/canine guidance and flat posterior occlusion, and in these cases the use of average values for the condylar inclination and the Bennett angle settings are sufficient. The condylar inclination relative to the Frankfort horizontal plane or the nearly equivalent axis-orbital plane is adjusted to the average setting of 45° and the incisal guidance to 10°. For the final instrumented occlusal analysis or as a prelude to extensive prosthodontic restoration, the articulator should be programmed to the patient's individual parameters. This is even more important when the patient does not have the use of definite eccentric guiding surfaces. The clinical relevance of programmed articulator joints depends not only upon the quality of the movement tracings, but also on the precision of the centric jaw relation record. The adjustment of the articulator for analysis of movements only serves to approximate a perfect movement simulation. It is only the mobility of the teeth that limits the possibility of a perfect reproduction of the patient's individual jaw movements.





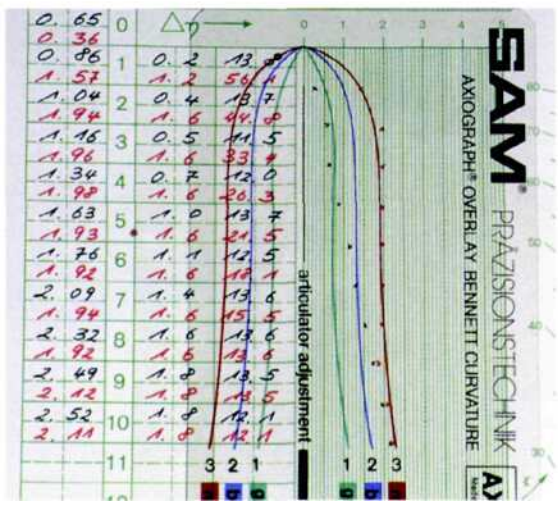
735 Drawing the reference plane
Left: The reference guide (Axiomatic) is mounted on the inner aspect of the right side-arm of the flag bow and adjusted so that the lower edge of the guide lies at the same level as the tip of the orbital pointer.

Right: The metal ruler is positioned to form a line from the reference guide to the red starting point of the hinge axis path, and this reference line is drawn on the registration grid.



736 Measuring the curvature and inclination of the condylar path
Left: The special measuring loupe is used to measure the condylar path.

Right: The base line of the angle scale covers the reference line on the registration grid. The zero point of the angle scale lies over the marked axis point. The angle of the condylar path is read from the 10-mm mark. Any curvature of the path is determined by comparison with the radii of curvature in the measuring loupe.



737 Estimation of the mediotrusive paths
Left: With the aid of the overlay film, the Bennett angle is determined and the closest matching Bennett guide is selected.

Right: In the SAM system, Bennett guides with four different curvatures and condylar paths with three different curvatures are available for customizing the articulator joints.

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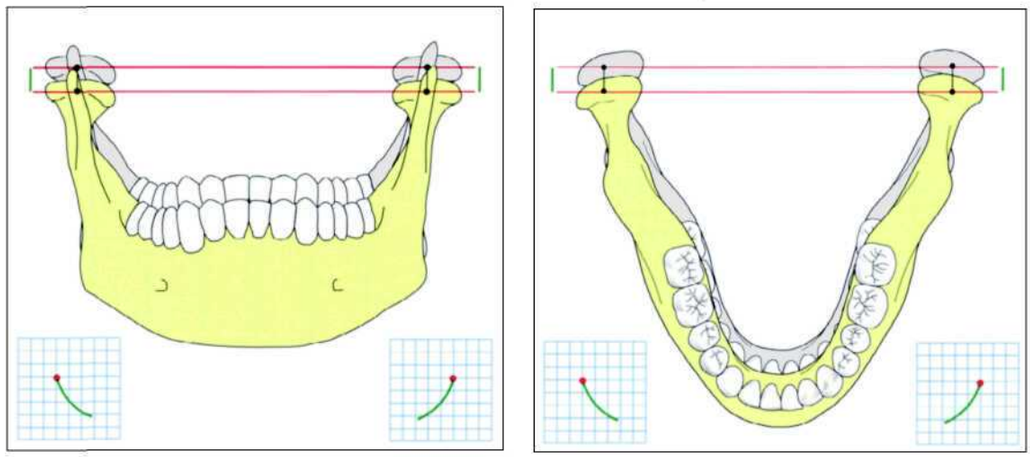
Hinge Axis Tracings (Axiograms) as Projection Phenomena

During extra-articular tracing procedures a distance exists between the place of registration (tip of the tracing pencil or receiving sensors) and the joint being analyzed. Therefore exaggerated tracings of the hinge axis paths (axiograms) can easily arise through projection phenomena (Klett 1982a). It is important that, in addition to the paraxial effect of an incorrectly located axis, this projection phenomenon be taken into account for a correct interpretation of the tracings. The only situation in which there is no projection distortion on the axiogram is one in which both condyles start their protrusive and retrusive movements simultaneously and with equal speed over condylar paths that are identical in curvature and length. If, on the other hand, the two condyles are asynchronous in their movements and travel asymmetrical paths, as is the rule, then the axiographic tracing will be malproportioned, flattened, shortened, or lengthened. This effect is especially noticeable in mediotrusion in which the movement of the working condyle is reproduced as a distorted, backward-curving laterotrusion path. This projection phenomenon increases with increased distance of the recording point from the temporomandibular joint.

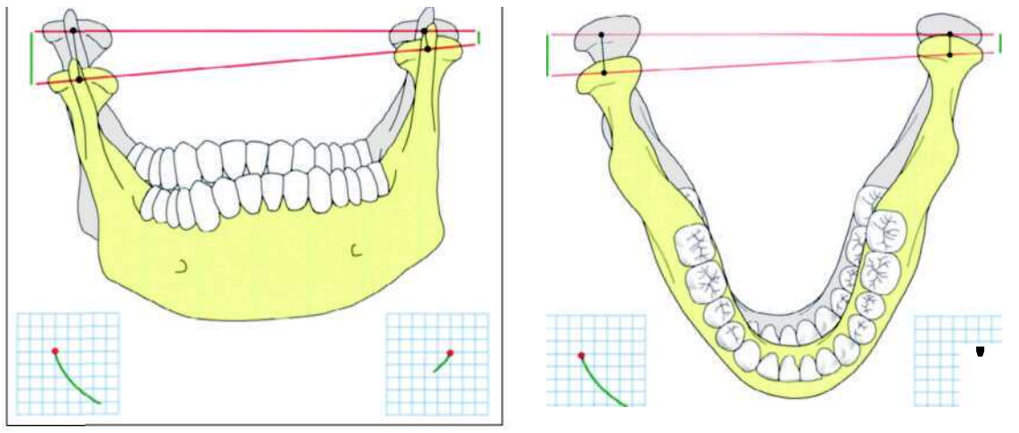
738 Parallel movement of the hinge axis
Left: The condylar pathways can be accurately reproduced without regard to the distance between recording flag and joint only if both condyles move synchronously along paths that are identical in direction, length, and curvature.

Right: The same situation viewed from above.



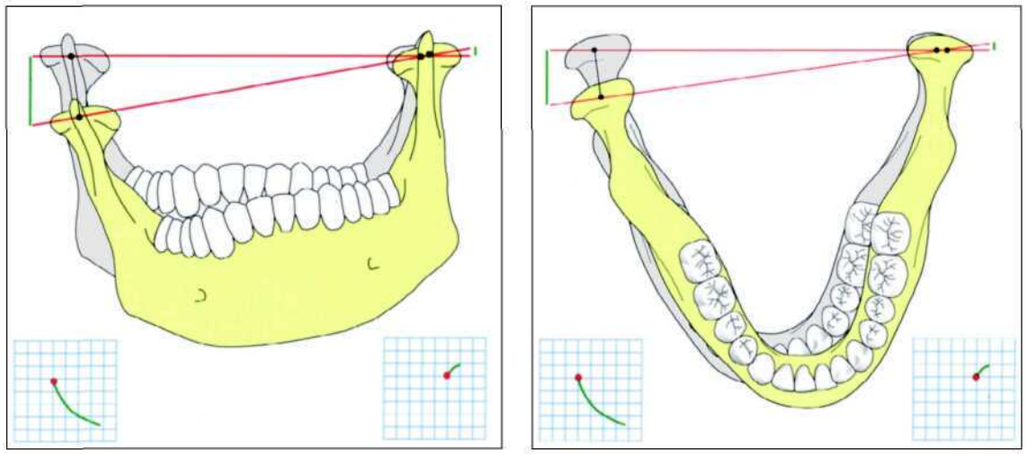
739 Unequal protrusion
Left If one condyle (here the left) follows a path that is flatter than that of the other condyle, the resulting tracings will be even flatter than the actual path on the first side and steeper than the actual path on the opposite side.

Right: If one condyle lags behind the other in its protrusive movement, the axiograph tracing of the slower condyle (here the left) will be flatter and shorter than the actual condylar path while the tracing of the leading condyle will be drawn longer and steeper.



740 Mediotrusion and laterotrusion
Left: An axiograph of the mediotrusive side (right) will be steeper and longer than the actual condylar path, while the movement of the laterotrusive condyle will be completely misrepresented by the tracing as a posterosuperior retrusive path.

Right: Superior view of the same situation.



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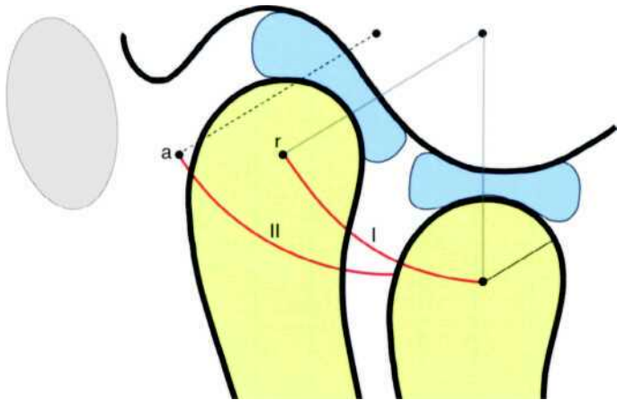
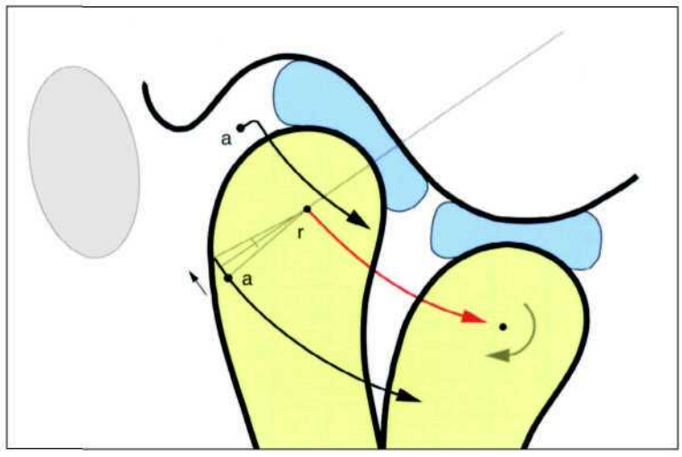
Effect of an Incorrectly Located Hinge Axis on the Axiograms

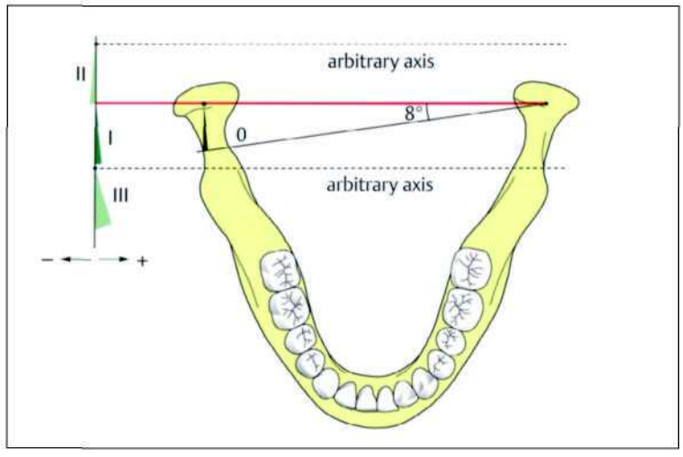
Mandibular movement registration procedures that make tracings from an incorrectly located hinge axis run the risk of producing a distorted representation of the actual movement of the axis. Thus a clinically significant change in position of the condyle can be reduced to an almost point-like marking, while a pure rotation can appear as a gliding movement. Combined rotating and translating movements of the mandible may be traced incorrectly depending upon the rotational component. This phenomenon can be used to test for correct location of the axis. Precise determination of the axis is proven when there is minimal difference between the tracings of protrusive and opening movements (Kohno 1972, Lotzmann 1987, Nagerl et al. 1991). If protrusive and retrusive mandibular movements are not accompanied by opening and closing of the mouth, then the precision of the hinge axis location bears no clinical relevance to the quality of the axiograms. The curvature and length of the tracings are unchanged. On the other hand, with mediotrusive movement the measurement of the Bennett angle can be affected.



741 Effect of an incorrectly located axis on a rotation-free protrusive tracing
A protrusive tracing (II) starting from an incorrectly located hinge axis (a) is identical in curvature, length, and inclination to a tracing (I) made from a point over the true axis (r).



742 Effect of an incorrectly located axis on an opening tracing
Depending on the position of the tracing axis (a) relative to the true axis (r), the axiograph will be more or less distorted. The path may be either elongated or run above or below the true path (red). From this it follows that a direct comparison of the protrusive and opening tracings can serve to test the correctness of the axis location. Both tracings should be virtually identical (Lotzmann 1990a).



743 Effect of an incorrectly located axis on the mediotrusive tracing
If the axiographic tracings are made over an incorrect axis (broken lines), which lies either posterior or anterior to the true hinge axis (red), the Bennett angle will appear either smaller (II) or greater (III) than when measured over the true axis (I).

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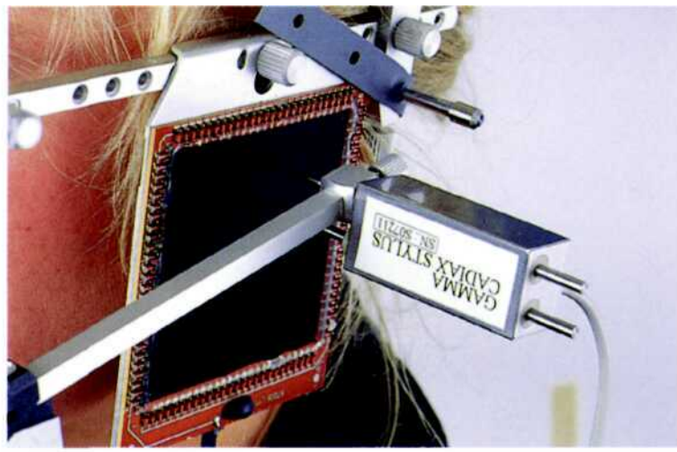
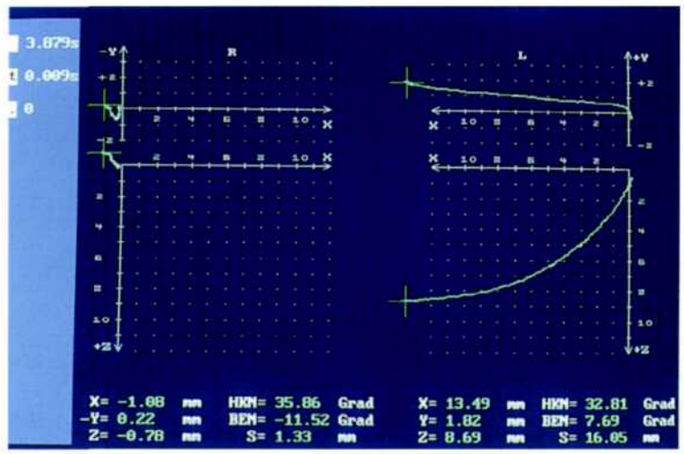
Electronic Paraocclusal Axiograpy

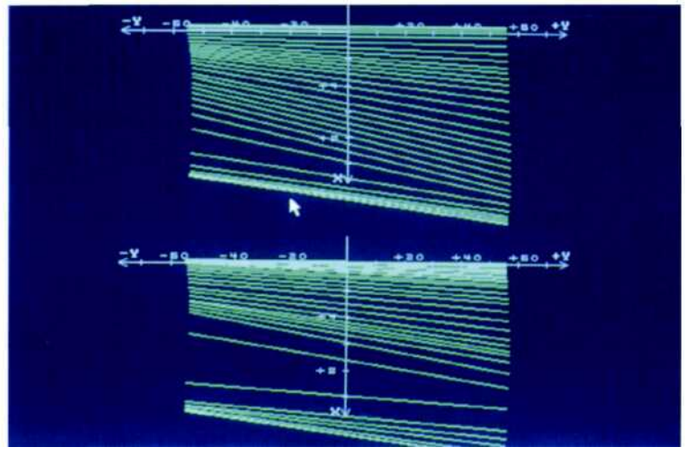
In recent years a number of electronic registration procedures for recording mandibular movements, both close to the axis and at a distance from the axis, have been described (Gillings 1967, Korber 1971, Burckhardt 1982, Klett 1982b, Meyer and dal Ri 1985). Systems in which new attachments can be made to the conventional axiograph will be of special interest to practitioners already familiar with mechanical axiography. The principle of electronic axiography can be traced back to Meyer and dal Ri (1985). They replaced the mechanical analog dial with a high-resolution electronic sensor and substituted a resistance foil for the recording graph paper. This made it possible for the first time to electronically record a point on the hinge axis in three dimensions. Similarly operating systems that are commercially available are the Axitron (by SAM) and the Cadiax System (by Gamma). Complementing the conventional axiograph with electronic sensors offers the advantage of computerized determination of measurements, data processing and documentation of axis displacements. Besides the improved spatial resolution of the movement paths, a decisive advantage is that the movements recorded outside the joint, and therefore distorted, can be corrected to coincide with the



744 Electronic axiography
The Cadiax-Recording-System (by Gamma), consisting of two sensors with double styli, two recording flags, insulation amplifier, and a foot pedal, allows computerized determination of hinge axis movements. Simultaneous tracing of both axis points makes direct correction of the axiograph for the patient's intercondylar distance possible.



745 Axiograph of a tooth-guided right lateral movement
Graphic PC representation of the hinge axis paths assisted by the Cadiax software. The two lower systems of coordinates represent movements in the sagittal plane while the upper systems plot the same movements in the horizontal plane. In the lower margin of the picture the numerical values are given for the positions of the crosshairs.



746 Profile of hinge axis movement
In this type of display, the lines connecting the right and left axis points (hinge axis) at different points in time are projected in both the horizontal plane (top) and frontal plane (bottom). This provides information on the relative acceleration of the two condyles.

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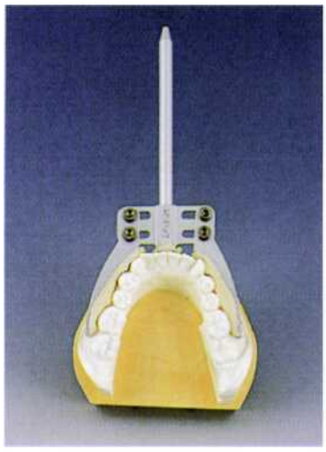
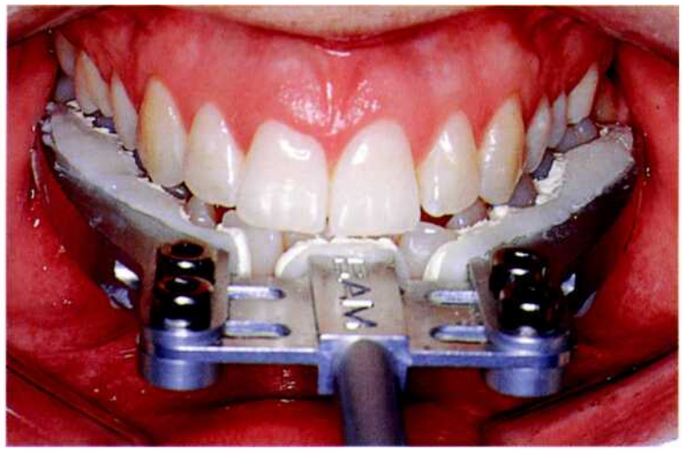
actual paths of movement within the joint. This correction of the tracings for the intercondylar distance naturally requires that recordings for the two joints be made simultaneously.

Still another advantage is the analysis of the speed and acceleration of movements of the axis which can provide information on the neuromuscular coordination of movements and mechanical obstructions of the joint. Both the Cadiax System and the String Condylocomp System can also measure rotation of the hinge axis and thereby determine, although with reduced precision, the calculated representation of any point on the mandible (e.g. incisal point). To be able to fully utilize the diagnostic capabilities, the face bow should be attached to the teeth without obscuring their occlusal surfaces. Only in this way can tracings of free and tooth-guided movements be compared directly with one another to determine whether or not the occlusal guidance exercises dominance over the temporomandibular joints. Axiograms of movements made by passive manipulation techniques can add worthwhile information to a manual functional analysis by providing, for example, documentation of the loading direction.

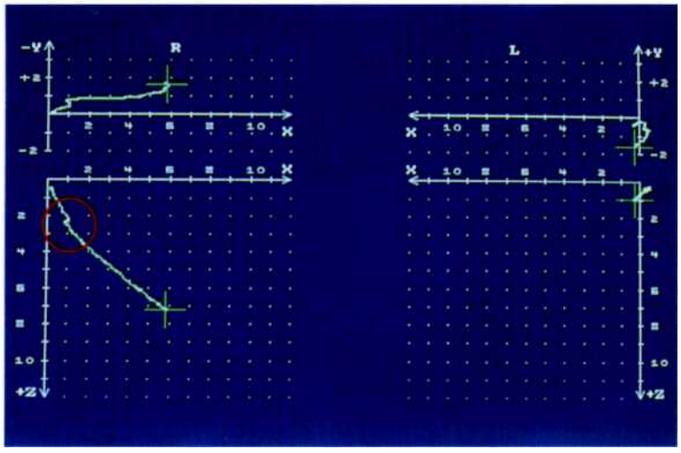




747 Occlusion-free attachment of the mandibular recording bow
After the adapter is fitted to the teeth it is attached with a zinc phosphate cement (e.g. Harvard) or a polycarboxylate cement (e.g. Durelon).

Left: The paraocclusal registration adapter (Axiodapt) is adapted to a cast of the mandibular arch by adding cold-cure acrylic. An upper cast is placed in maximal occlusion against the lower cast to ensure that the adapter will not interfere with the occlusion.

748 Paraocclusal axiography of a left lateral excursion
Cadiax sensors are attached to the Axiograph III. In addition to translational movements, the double styluses also permit registration of rotation of the hinge axis.



749 Testing the influence of the occlusion
The axiograph, corrected for projection errors, reveals that during a tooth-guided movement of the mandible to the left a strong balancing contact is causing a slight distraction of the condyle on the balancing side (circled in red).

Left The nonworking interference on the upper and lower second molars causes a distinct discussion of the other teeth, both anterior and posterior.

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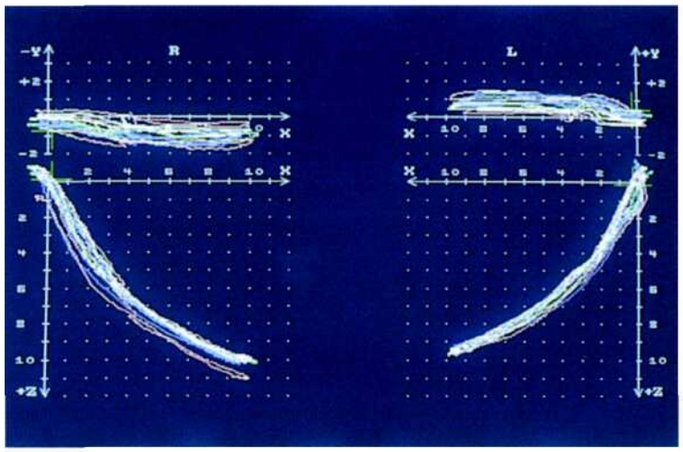
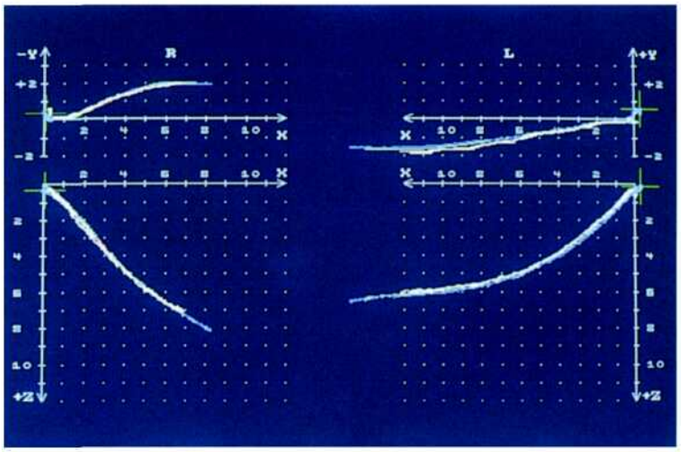
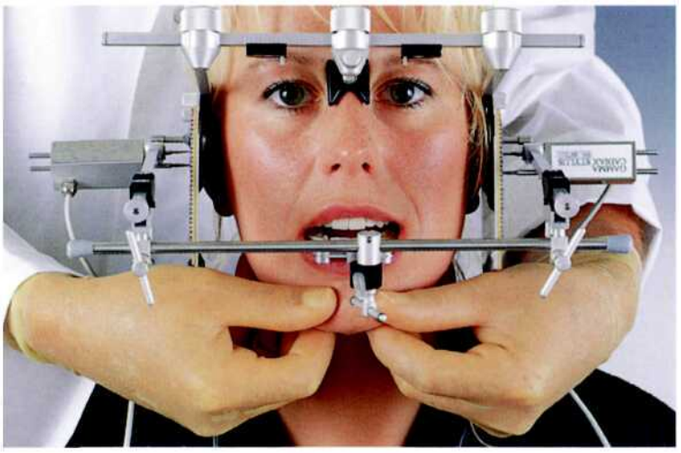
750 Superimposition of multiple axiographs
The Cadiax software also allows the overlaying of multiple color-coded tracings of jaw movements. The wide distribution of the tracings shown here could indicate recording artifacts (loosened adapter, loose flag bow), pronounced neuromuscular incoordination, and/or "greater than normal play in the joints."



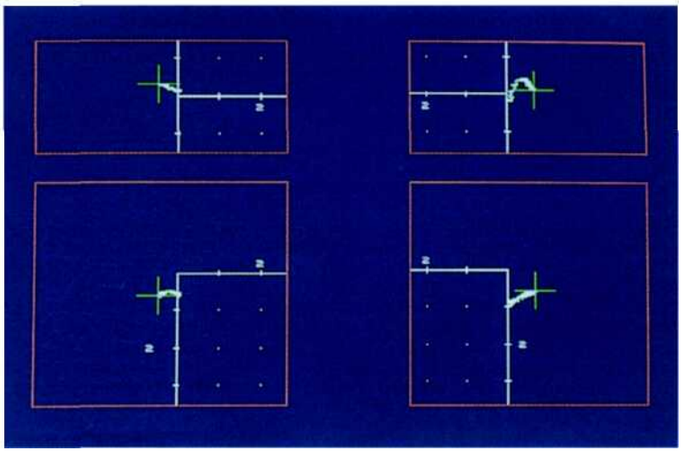
751 Direct comparison of tooth-guided and free protrusive tracings
Movements made with the teeth in contact can be compared directly with movements made in the same direction without tooth contact to determine whether there is harmony between tooth guidance and joint guidance. The asymmetrical pattern of free protrusive movement shown here leads one to suspect that neuromuscular adaptation to asymmetrical tooth guidance has taken place.



752 Bimanual grasp technique for upward manipulation of the mandible
By using the Dawson grasp, an additional superior or anterosuperior force can be exerted on the temporomandibular joints. If the resilience of the joint does not allow a slight superior displacement of the axis points, then this indicates the presence of a functional compression of the joints.



753 Display of the space for retrusive movement in the temporomandibular joints
These paths of movement displayed in the sagittal plane (lower rectangles) and horizontal plane (upper rectangles) begin from the maximal intercuspation position. The mandible was guided manually into its rearmost position (green crosses). The retrusion paths should appear equal and should not exceed 1.5 mm in length.



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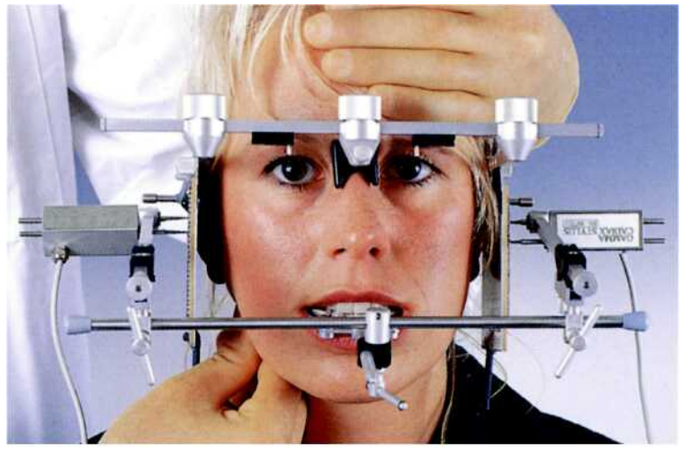
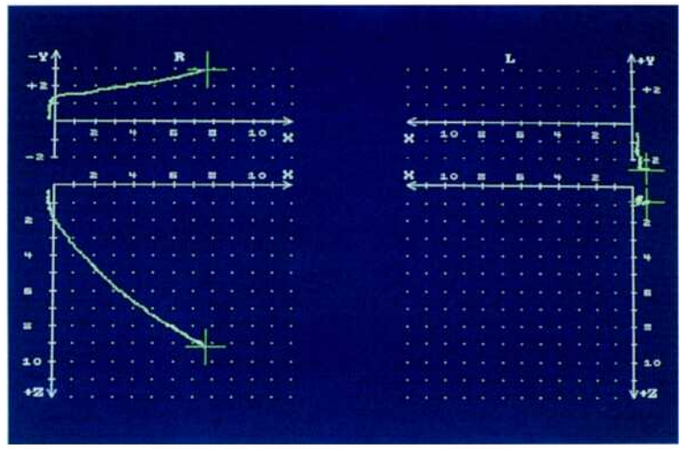
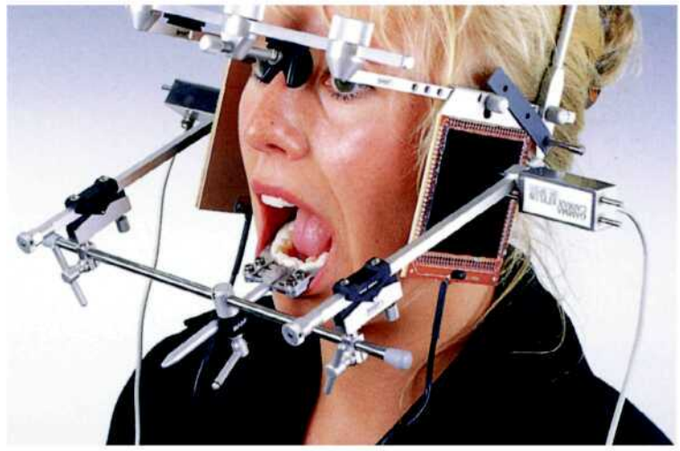


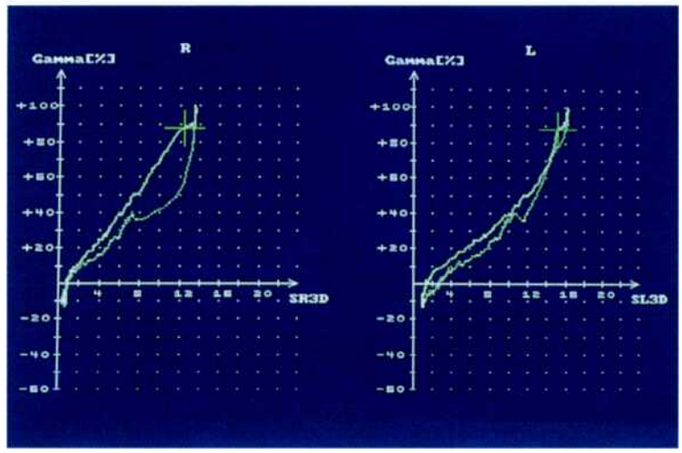
754 Manipulation technique to induce mediotrusion
To record the space of the temporomandibular joint used predominantly for parafunctional movements, the tracing of the free medial excursion is supplemented by a manipulated medial condylar movement.



755 Tracing of an induced medial excursion
When a medially directed force is applied to the angle of the jaw, the condyle on that side initially moves medially and downward.



756 Recording of the opening movement
Because of the elastic deformation of the arch of the mandible, there is a chance that when the mouth is opened wide the registration adapter may become loosened from the teeth. For this reason, tracings of the maximum opening and closing movements should be made at the conclusion of the recording appointment.



757 Diagram of translating and rotating movements
The Cadiax software offers the capability of representing the translational and rotational components of a movement in diagram form. From this, conclusions can be drawn about the coordination of the mandibular movements.

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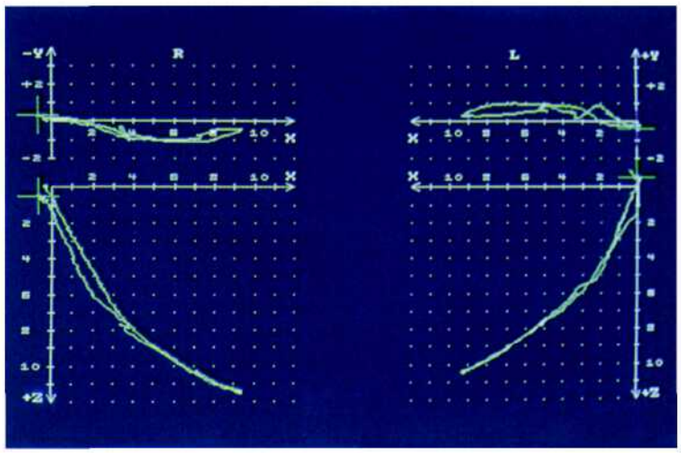
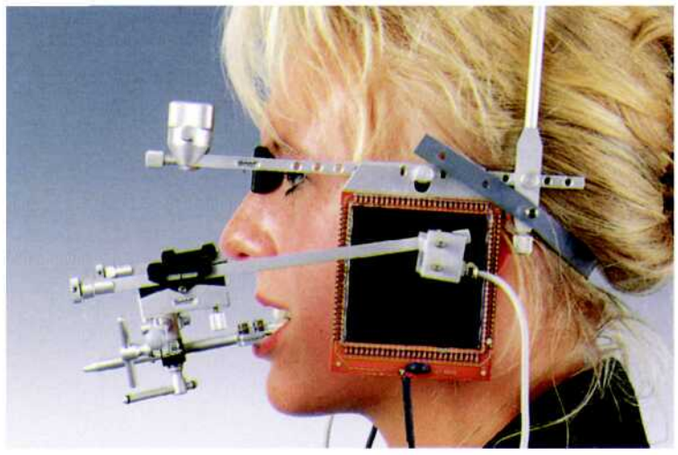
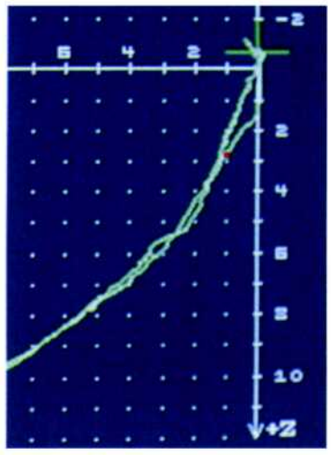
758 Axiographic representation of deranged temporomandibular joint function
The left protrusive and retrusive tracings suggest anterior disk displacement with repositioning. Manual functional analysis confirms this suspicion. Presumably the striking difference in the paths on the right side is of neuromuscular origin. At the present time there is no conclusive evidence that the cause of joint clicking phenomena can be reliably discerned from axiographic tracings alone (Rammelsberg 1998).



759 Defining the treatment position of the mandible
In individual cases paraocclusal axiography may also be helpful in defining the treatment position of the hinge axis points, and thereby of the condyles.

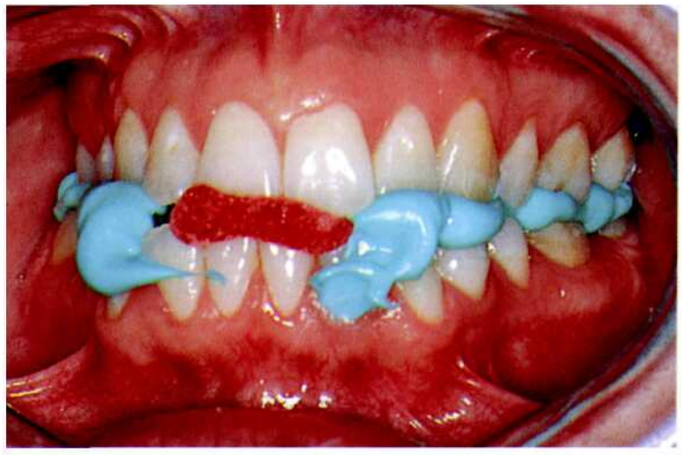
Right: Here, the most retruded condylar position at which the disk is in its correct relation to the condyle has been determined by using the axiographic tracing (red dot).

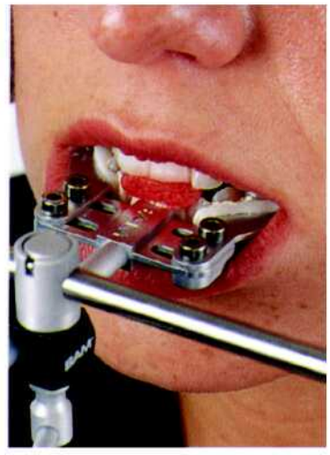




760 Interocclusal registration
The axiograph is removed. The anterior bite index serves to keep the mandible in the treatment position while the interocclusal relation is recorded with a firm-setting silicone or other suitable material.

Right: While monitoring the jaw relationship with the axiograph, the defined mandibular position is fixed by means of an anterior index made of cold-curing resin.





761 Mounting the casts
The interocclusal record is used to mount the mandibular cast in the therapeutic position previously determined with the help of the axiograph. The occlusal splint for occlusal stabilization is fabricated at this intermaxillary relationship.

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Diagnoses and Classifications

The most important aspect of a classification system is not that the divisions must be accepted by all practitioners, but rather that it contain specific diagnoses that are uniformly and consistently defined for everyone. This of course assumes that not only will uniform definitions be taught in the clinics and then put to use in clinical practice, but that they will also be employed in making decisions. For many decades collective terms such as "temporomandibular disorder" (Wright 1920, Goodfriend 1933), "Costen's syndrome" (Costen 1956), "temporomandibular pain syndrome" (Schwartz 1956), "TMJ dysfunction syndrome" (Shore 1959), "pain dysfunction syndrome" (Voss 1964), "myofascial pain dysfunction syndrome" (Laskin 1969), "myoarthropathy" (Schulte 1970, Graber 1971), and "internal derangement" (Farrar 1972a) have been used as diagnoses. All of these terms, however, are too loosely defined and do not provide guidance toward a specific treatment.

More precise classifications are based upon tissue-specific symptoms (Fricton et al. 1989), etiological structural and functional disturbances (Laskin 1982), the frequency of their occurrence (McCarthy 1985), and upon existing medical classifications (Stegenga et al. 1989a,b, Okeson 1996). The correlation of dental classifications with those of general medicine presents three significant advantages:

- Recognition by the medical profession of functional disturbances of the masticatory system increases awareness of the need for a specific diagnostic system to differentiate these problems from other disorders in the head and neck region.
- Inclusion of masticatory disturbances within a larger medical classification increases acceptance of the necessity for treatment and the readiness for urgently needed interdisciplinary treatment.
- A medical framework facilitates the dissemination and acceptance of specific semantic definitions and specific diagnostic criteria.

The classification we use borrows some of its content from Bell (1986), Fricton et al. (1989), and Okeson (1996). This classification is also found in the guidelines of the American Academy of Orofacial Pain (Okeson 1996). In addition, it is a component of the widely accepted classification of the International Headache Society (1988). In this atlas we have made it a high priority that all definitions of tissue-specific diagnoses agree with the generally accepted national and international definitions. We define some of the diagnostic criteria even more specifically and strictly because manual functional analysis permits a highly specific differentiation.

This chapter, because of its practice-oriented focus, differentiates between primary and secondary (dysfunction-related) diseases. The primary diseases are often noticed during the clinical inspection and are confirmed essentially through imaging procedures. The secondary functional disturbances, on the other hand, usually require specific functional analytical procedures to arrive at a sure clinical diagnosis. The individual tissue-specific diagnoses are divided into arthrogenic and myogenic lesions and are arranged within these categories according to their structural characteristics (= damaged anatomical structures). The reader is already familiar with the latter from the chapters "Anatomy" and "Manual Functional Analysis." For clearer understanding, the color coding of the anatomical structures has been retained.

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Classification of Primary Joint Diseases

Primary joint diseases include *congenital* and *developmental* alterations of the temporomandibular joints. Leading among these are hyperplasia, hypoplasia, and aplasia of the condyles, syndromes with temporomandibular joint involvement, and systemic diseases. Fractures and tumors are also included with these. In contrast to the function-related joint diseases, diagnosis and treatment is largely based on imaging procedures. The chief function of imaging procedures in everyday functional diagnosis is therefore to conclusively exclude primary joint diseases.

Naturally, a general clinical examination and inspection of the patient is conducted before arranging for imaging procedures. As a rule, a patient diagnosed with a primary joint disease in a dental or orthodontic practice is referred to a qualified center for treatment.

Because in many cases the etiology is apparent and the clinical symptoms are unequivocal, there are few contradictions in the literature regarding classification of primary joint diseases (Bell 1986, Kaplan and Assael 1991, Zarb et al. 1994, Okeson 1998).

762 Primary diseases of the temporomandibular joint
Classification of the most important primary diseases of the temporomandibular joint with literature references for additional reading.

Classification	Diagnosis	Literature references
Developmental abnormalities	Hyperplasia of coronoid process Condylar hyperplasia Condylar hyperplasia Condylar aplasia Congenital syndrome	Gross et al. 1997 Isberg and Eliasson 1990 Nakata et al. 1995 Krogstad 1997 Polley and Figueroa 1997 Posnick 1997 1998
Inflammations	Bacterial arthritis Rheumatoid arthritis Juvenile chronic arthritis Free intra-articular bodies	Leighty et al. 1993 Scutellari and Orzinolo 1998 Larheim et al. 1992 Sarma and Dave 1991 Ikebe et al. 1998 Duvoisin et al. 1990
Fractures	Classification of condylar fractures Classification of disk displacements associated with condylar fractures	Spiessl and Schroll 1972 Bumann et al. 1993
Ankylosis	Fibrous ankylosis Bony ankylosis	Nitzan and Dolwick 1989 Moses and Lo 1995 McCain et al. 1992 Lello 1990
Tumors	Primary benign tumor Primary malignant tumor Metastases	Bavitz and Chewning 1990 Kreutzinger 1994 DeBoom et al. 1985 Glaser et al. 1997 Johal et al. 1994
Cysts	Ganglionic cyst Synovial cyst Epidermoid cyst Aneurysmal bone cyst	Chang et al. 1997 Bonanacci et al. 1996 Weinberg and Kryshtalkyi 1995 Svensson and Isacsson 1993
Other	Systemic lupus erythematosus Avascular necrosis Akromegaly Gout	Jonsson et al. 1983 Donaldson 1995 Schellhas et al. 1989 Hampton 1987 Gross et al. 1987

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Classification of Secondary Joint Diseases

Over the past several decades a large number of classifications for *functional,* or so-called secondary joint diseases, have been proposed. A classification is not only the foundation for a "common language," it is also necessary to identify and define other conditions that are primarily nondental. In this respect, the inclusion of functional temporomandibular joint diseases in a medically oriented *classification of headaches, cranial neuralgias, and facial pain* like that of the International Headache Society (Okeson 1998) makes sense. The classification adopted by the American Academy of Orofacial Pain (McNeill 1993) is therefore recommended as the basis for international communication.

As was made clear in the chapter on manual functional analysis, these academic guidelines must be made more specific for the sake of making a differential diagnosis that is relevant to practice and treatment. With reference to the previous chapter and to facilitate the general understanding, a classification of affected structural components is presented in Figure 763. Only the loading vector is relevant to the treatment.

Structure	Tissue-specific diagnosis	Possible loading vectors*
Joint surfaces	Cartilaginous hypertrophy	A, AS, S, LS, MS
	Osteoarthrosis	A, AS, S, LS, MS
	Osteoarthritis	A, AS, S, LS, MS
	Ankylosis	Nonspecific
Disk	Deformed disk	A, AS, S, PS, SSL
	Perforated disk	
Bilaminar zone	Capsulitis	S, LS, MS, PS, PSL, P, SL
	Perforation	A, AS
	Partial disk displacement with reduction	P, PS, PL, PSL
	Total disk displacement with reduction	P, PS, PL, PSL
	Disk displacement with occasional reduction	P, PS, PL, PSL
	Disk displacement without reduction	P, PS, PL, PSL
	Disk displacement with disk adhesion	P, PS, PL, PSL
Joint capsule	Capsulitis	L, M, A, I
	Vertical hypomobility	S, LS, MS
	Sagittal hypomobility	P, PS, PL, PSL
	Generalized fibrosis	Nonspecific
	Posterior disk displacement	A
	Synovialitis	Nonspecific
	Acute arthritis	Nonspecific
Ligaments	Luxation of condyle	Nonspecific
	Hypermobility of condyle	Nonspecific
	Vertical hypermobility of capsule	I
	Posterior hypermobility of capsule	A
	Clicking sound from lateral/medial ligaments	I or secondary to trauma
	Insertion tenopathy	I or A
Muscles	Myofascial pain	Nonspecific
	Myositis	Nonspecific
	Spasm	Nonspecific
	Funktional muscle contraction	In direction of muscle fibers
	Tendonitis	In direction of muscle fibers
	Insertion tenopathy	In direction of muscle fibers

763 Classification of secondary diseases of the temporomandibular joint
This classification corresponds to the information in the chapter "Anatomy" and the groups are separated by individual anatomical structures according to the steps in the clinical examination procedure. For everyday clinical communication the individual tissue-specific diagnoses are especially important. In the right-hand column are listed the theoretically possible loading vectors for each condition. The direction of a particular loading vector can be determined for each patient through systematic use of the manual functional analysis examination technique. For certain diagnoses, however, only a nonspecific loading vector can be deduced. In such cases only a general symptomatic treatment is possible at that particular time. After the nonspecific pain symptoms have been relieved, it is usually possible to arrive at a more specific differentiation with the help of manual examination methods.

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Hyperplasia, Hypoplasia, and Aplasia of the Condylar Process

A unilateral hyperplasia, hypoplasia, or aplasia may cause facial asymmetry that is recognizable clinically (Westesson et al. 1994). It is often difficult to distinguish clinically which side is "normal" and which is either "too long" or "too short."

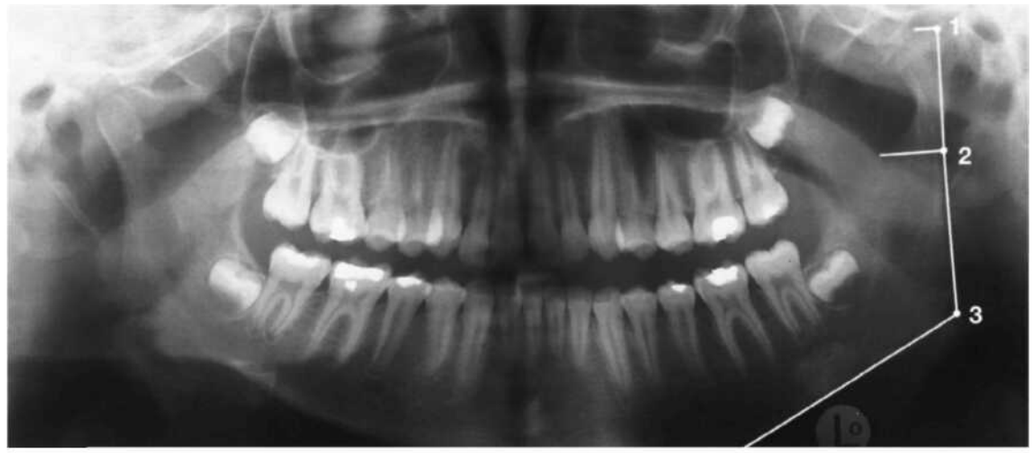
- Hyperplasia can be traced back to a primary increased reactivity of the condylar cartilage, or to a secondary adaptation to skeletal or occlusal conditions (Gola et al. 1996). The former cause can be reliably demonstrated during the active stage with a scintograph (Gray et al. 1994). A 10% enrichment of nucleotides in side-by-side comparisons is considered clinically significant (Pogrel 1985). A benign tumor may be concealed behind an active hyperplasia (Papavasiliou et al. 1983, de Bont et al. 1985).

Hypoplasia can be iatrogenic, appearing following orthognathic jaw surgery (De Clercq et al. 1994, Nishimura 1997, Kawamata et al. 1998).

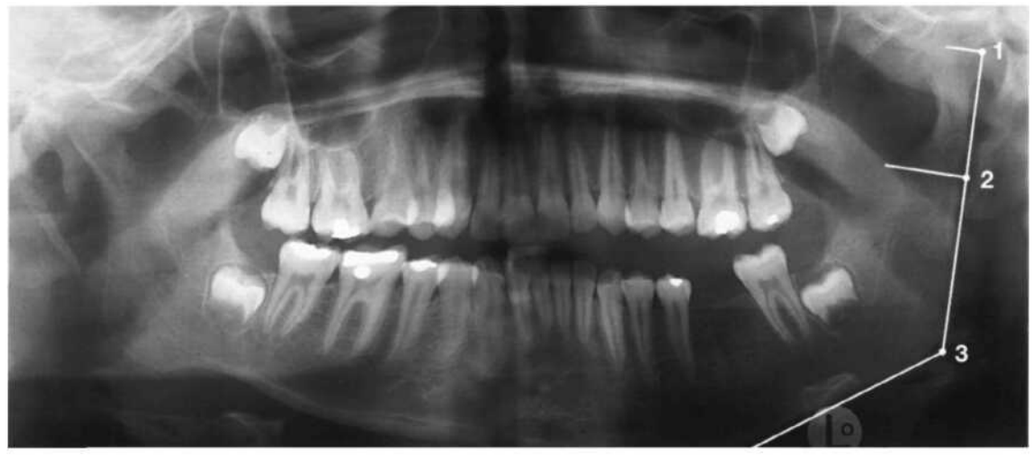
Aplasia can be observed in hemifacial microsomia, Goldenhar syndrome, and Treacher Collins' syndrome (Gorlin et al. 1990, Krogstad 1997). It very seldom appears independently of a syndrome (Prowler and Glassman 1954).

Female patient with hyperplasia on left side

764 Condition at age 11 years and 5 months before orthodontic treatment
A comparison of the sides in a panoramic radiograph reveals abnormal formation of the left condyle. The relation of the distances between the condyle (1), the coronoid notch (2), and gonion (3) lead one to suspect a hyperplasia of the left condylar process. There are no striking findings in the occlusion beyond some tipping and rotation of teeth.

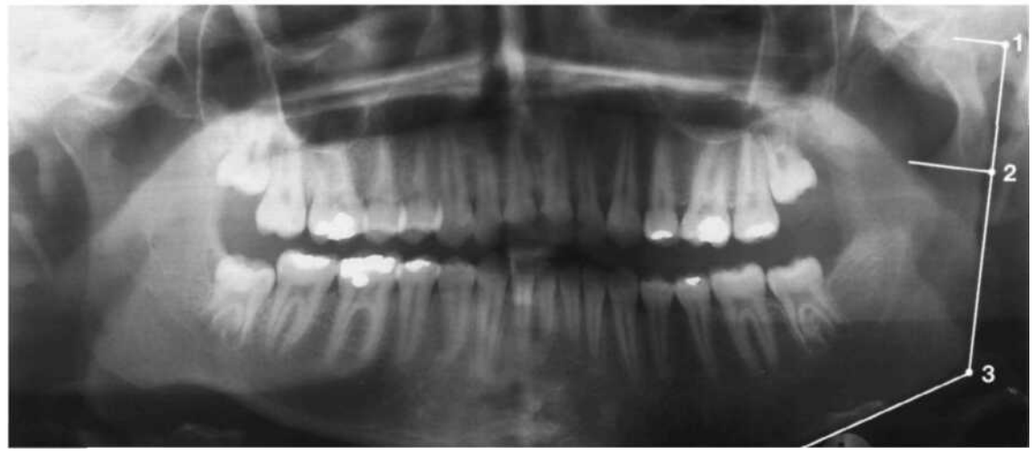


765 Condition after 1.5 years
Clinically a lateral open bite has developed with intrusion of the tongue between the occlusal surfaces. The lines representing the relation of the distances between the condyle (1), the coronoid notch (2), and gonion (3) indicate a shift in favor of the ascending ramus. The lower left first molar has been extracted because of a painful pulpitis.



766 Condition after 3 years
Even though a good occlusion had been established in the meantime, growth in the ascending ramus has progressed further. This was accompanied by a recurrence of the lateral open bite. A scintigraph showed a slightly greater accumulation of nucleotides on the left side. Because benign tumors in the condylar region can present a similar picture, the possible differential diagnoses must be discussed thoroughly with the patient.

Collection M. Roloff



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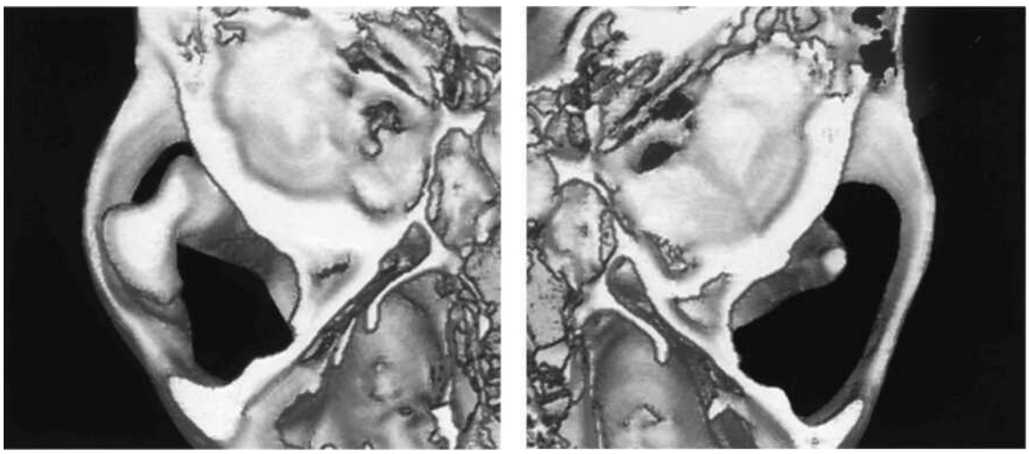
Hyperplasia of the Coronoid Process

As with the condyle, the coronoid process can be enlarged through autonomous growth or a secondary adaptive process (Giacomuzzi 1986, Totsuka and Fukuda 1991, Kerscher et al. 1993). Patients with congenital restriction of jaw opening and those with limited opening because of disk displacement without repositioning have longer coronoid processes than subjects in a healthy control group (Isberg and Eliasson 1990). With extensive hyperplasia, the process can strike against the inside of the zygomatic arch as the jaw is opened, thereby causing *limited mouth opening.* Occasionally the lateral movements are also restricted (Gross et al. 1997). Lengthening of the coronoid process can be identified with relative ease in a panoramic radiograph (Hicks and Iverson 1993, Hönig et al. 1993, 1994).

The treatment of choice is *surgical removal* (Constantinidis et al. 1997, Chen et al. 1998, Manganaro 1998). A CT scan with three-dimensional reconstruction is indicated for precision planning of the operation (Totsuka et al. 1990). MRI, on the other hand, is necessary only if there are postoperative complications (Pregarz et al. 1998).

767 Panoramic radiograph
A 35-year-old male with hyperplasia of the right coronoid process and normal appearance on the left. Clinically there is a restricted mouth opening (RMO) of 25 mm. The cause for the RMO cannot be automatically deduced from the finding of an enlarged coronoid process. A causal relationship can be established only when the RMO is accompanied by a bony end-feel upon passive jaw opening (see also pp. 66f).

768 Measurement of coronoid process
The length of the coronoid process can be measured on a panoramic radiograph (Hönig et al. 1993) by joining the highest points on the condyies with a straight line. Normally the tip of the coronoid process lies below this line (left). If it extends more than 4 mm above the line, the coronoid process is considered to be enlarged. This does not necessarily cause an RMO, but it does go along with a reduced gonion angle (Isberg and Eliasson 1990).



769 CT
Left: Representation of the right coronoid process viewed from above, showing its mushroom-shaped enlargement. Clinically both the mouth opening and right lateral jaw movements are restricted. In this case the enlargement was caused by an osteochondroma. Clinically detected limitations of movement always depend upon the extent of the hyperplasia.

Right: Image of the unaffected left coronoid process in the cranial view.

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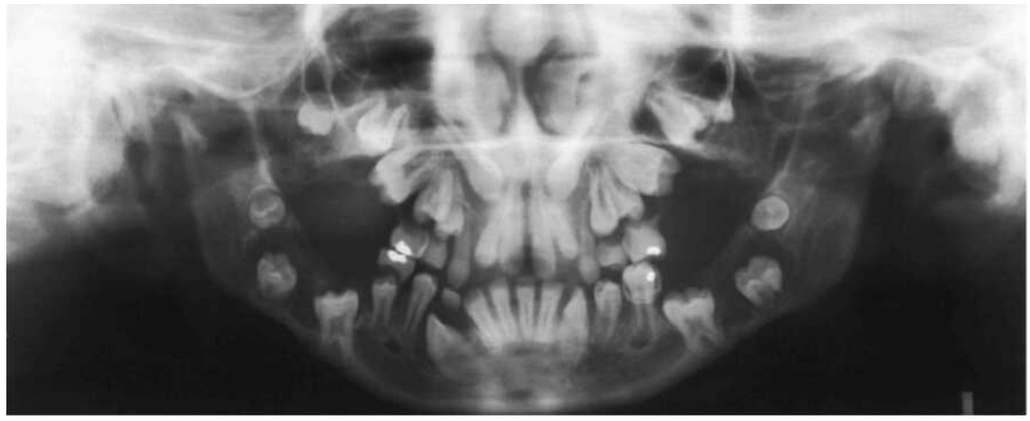
Congenital Malformations and Syndromes

A hyperplasia or aplasia of the ascending ramus of the mandible is frequently associated with *hemifacial microsomia* (Lauritzen et al. 1985), *Goldenhar syndrome* (Heffez and Doku 1984, Hoch and Hochban 1998), or *Trencher Collins' syndrome* (Posnick 1997). In addition to bony changes there are often marked abnormalities in the sizes of the surrounding muscles. The volume of the affected lateral pterygoid muscle may be only 20-35% that of the normal side (Kahl-Nieke and Fischbach 1998). With hemifacial microsomia all permanent first molars and all deciduous molars are significantly smaller than the teeth of normal individuals (Seow et al. 1998). Early functional orthodontic treatment of microfacial microsomia can have a positive effect on the development of the masticatory system as either a presurgical step or as the sole conservative treatment (Kahl-Nieke and Fischbach 1998).

Costochondral transplants (Lindqvist 1986, Svensson and Adell 1998) and traction appliances to stimulate bone growth (Klein and Howaldt 1995, McCormick et al. 1995, Diner et al. 1997, Polley and Figueroa 1997) are two methods that can help correct the abnormally short vertical dimension.

770 Mucopolysaccharidosis (Type VIb)
Panoramic radiograph of a 12-year-old girl. In this hereditary disease there is incomplete breakdown of dermatane sulfate and therefore its concentration in the tissues is increased (Sheridan et al. 1994, Nelson 1997, Byers et al. 1998). The disease manifests itself in the craniofacial region as cyst-like changes in the jaw bones, multiple unerupted teeth, delayed tooth eruption, and, due to its effect on the fibrocartilagenous joint surfaces, shortening of the ascending ramus.



771 Hemifacial hypoplasia of the right ascending ramus of the mandible
Panoramic radiograph of a 20-year-old female patient. There is nothing remarkable about the bone structure on the left side. At this age the treatment of choice is lengthening of the ascending ramus by means of an intraoral distraction osteogenesis appliance. In some cases a LeFort-I-Osteotomy is indicated. Notwithstanding the term "hemifacial," it is possible for both sides to be affected in a hemifacial microsomia (Yamashiro et al. 1997).

772 Coldenhar syndrome
Panoramic radiograph of a 10-year-old girl. The aplasia of the left condylar process (arrows) had not yet led to any significant secondary adaptations in the upper and lower dental arches, except that the midline of the mandible has shifted slightly to the left.
At this stage an attempt at conservative treatment is indicated. If this does not produce satisfactory results, one can fall back on corrective surgery later.

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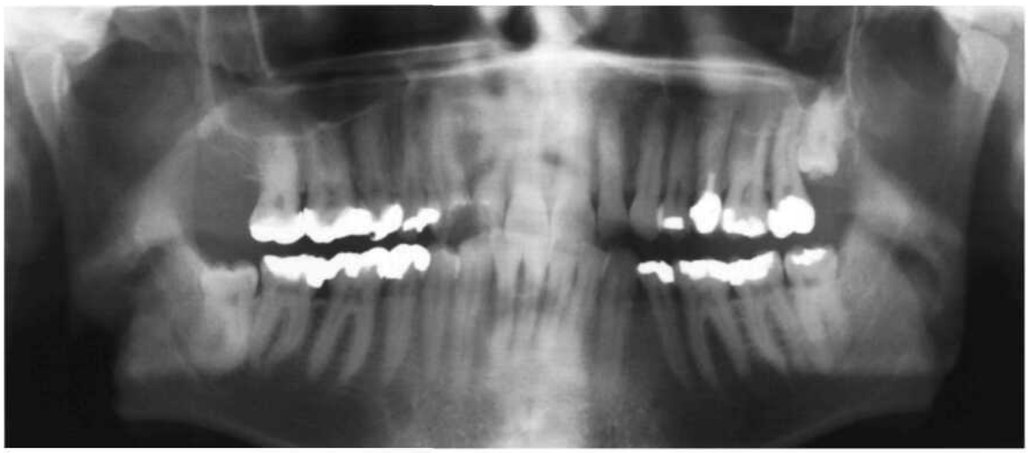
Acute Arthritis

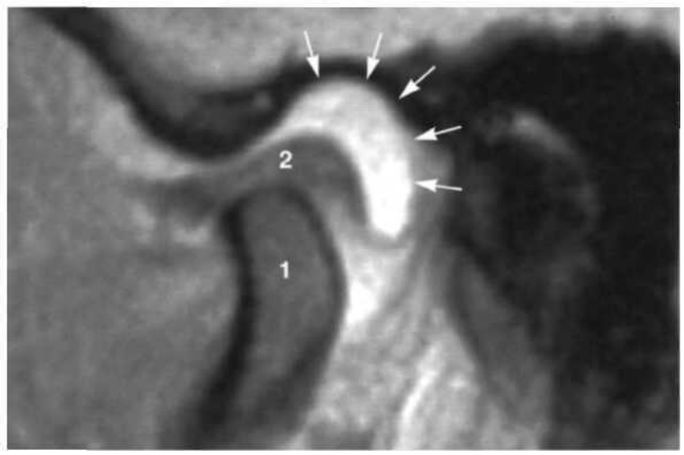
Acute arthritis can be traced back to a septic inflammation or a trauma. The relatively uncommon septic arthritis is usually due to *Staphylococcus aureus* (Dhanrajani and Khateery 1993, Leighty et al. 1993, Moses et al. 1998). Clinically, all passive compression manipulations are painful (= capsulitis with nonspecific load vector) and active movements are severely limited. There is infraocclusion on the affected side because of the protective reflex in response to pain. The joint effusion is clearly visible on MRI, especially with the T2 weighting. Analysis of the synovial fluid and a blood count confirm the clinical diagnosis. The primary *treatment* consists of drainage of the joint, administration of antibiotics, and keeping the jaws in the rest position. Secondarily, physiological jaw opening is restored through active physiotherapy. Inflammatory changes in the temporomandibular joint are always accompanied by temperature changes and alteration of the neuropeptides (Merritt et al. 1983, Appelgren et al. 1993). The higher the intra-articular temperature, the longer the clinical joint symptoms will persist (Kawano et al. 1989, 1993).



Acute arthritis

773 Normal-appearing jaws in a standard projection panoramic radiograph (incisal bite)
If this were compared with a radiograph made with the teeth in habitual occlusion, one would recognize that there is lateral infraocclusion as the result of a protective jaw position. But since this had already been confirmed clinically, there was no reason to subject the patient to more radiation. The purpose of the radiograph was for screening and to exclude the possibility of a fracture.

774 Habitual occlusion
In the presence of acute arthritis there is almost always an infraocclusion on the affected side. The magnitude can vary considerably from patient to patient. This 32-year-old man has acute arthritis with extensive edema of the joint resulting from trauma to the mandible. According to the patient's dental history, "all the teeth fit together" before the injury. The panoramic radiograph showed no evidence of a fracture and therefore no additional radiographs were necessary.



775 MRI of the acute effusion
This T2-weighted MRI at maximal jaw opening confirmed quite conclusively the presumptive clinical diagnosis of an acute joint edema. In a T1-weighted MRI a collection of fluid shows up as light gray, but in this T2-weighted image it appears white (arrows). The high contrast clearly demarcates the contours of the condyle (1) and disk (2). If the patient holds the jaws at rest position this type of edema will be almost completely resorbed within 14 days.

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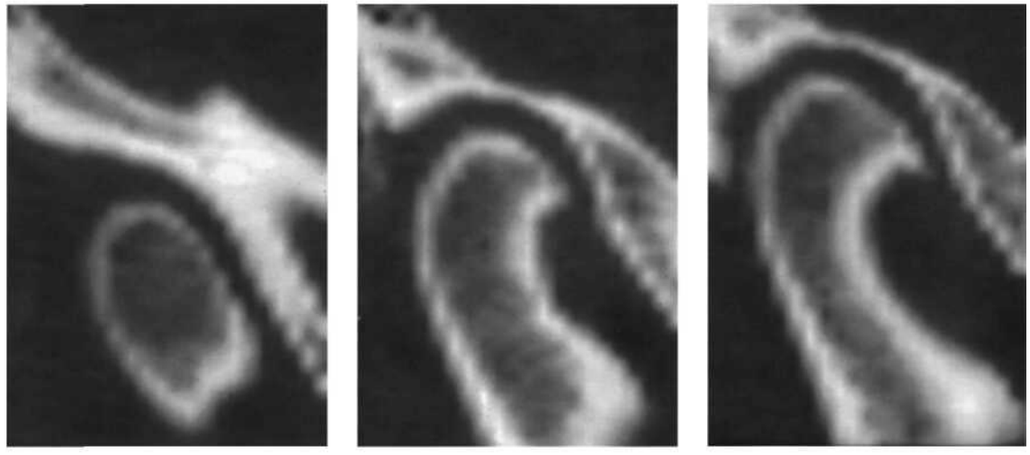
Rheumatoid Arthritis

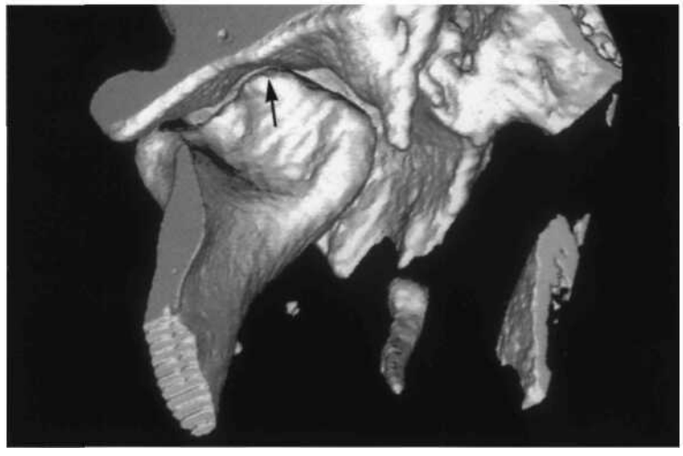
Rheumatoid arthritis (RA) is a systematic collagen disease of unknown etiology that is manifested chiefly in the joints (Schumacher et al. 1993, Kopp 1994). Its incidence is approximately three to five cases per 10 000 people (Kaipianen-Seppanen et al. 1996). Although osteoarthritis and RA have different causes, the tissue reaction is almost identical in both conditions. However, the inflammatory and degenerative changes are more rampant in RA (Gynther et al. 1997). The American Rheumatism Association lists seven criteria for the diagnosis of RA (Arnett et al. 1988). Whenever a patient meets four of these criteria the diagnosis is confirmed. The specificity of these criteria, however, is the object of controversy (Harrison et al. 1998). Involvement of the temporomandibular joint (approximately 30-50%) with RA is established through an additional eight criteria, whereby again at least four must be present (Kopp 1994). The most important clinical findings are reduced mouth opening (through active movement), crepitus (upon dynamic compression), pain or an endfeel that is *too hard* (during the joint play test), and an anterior open occlusal relationship ("open bite"). Physical therapy will improve mobility but not the pain symptoms (Tegelberg and Kopp 1996).

A 56-year-old woman with arthritis in both temporomandibular joints

776 Panoramic radiograph
The deformation of the condyles can be seen clearly in this standard projection. Were it not for the clinical evidence of a positive rheumatoid factor test and multiple joint involvement, however, this radiograph could just as well indicate an osteoarthrosis. In this case, imaging procedures cannot differentiate with certainty, but serve only for confirmation.



777 Computed tomograms
The additional step of making either conventional tomograms or computed tomograms can document dramatically the deformation of the bony joint surfaces, but the images neither provide additional diagnostic information nor lead to any new therapeutic procedures. As these tomograms of the lateral *(left),* centrolateral *(center),* and central *(right)* sections of the joint show, changes in the bone do not necessarily occur uniformly throughout, but can vary greatly from point to point.



778 Three-dimensional reconstruction
This spatial reconstruction from the CT data shows once more the morphological changes on the condyle, but from an anteroinferomedial point of view. The deformation caused by rheumatoid arthritis in the central portion of the condyle (arrow) can be seen. These impressive pictures must not mislead one into thinking that this type of imaging is important for the treatment otherthan as a presurgical planning tool or for the diagnosis of tumors.

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Juvenile Chronic Arthritis

The term *juvenile chronic arthritis* (JCA) indicates a rheumatoid arthritis that manifests itself before the 16th year and remains active for more than 3 months. In the past, the terms most frequently used were *juvenile rheumatoid arthritis* (Hu et al. 1996), *juvenile chronic arthritis* (Kjellberg 1995, EULAR = European League Against Rheumatism), and *chronic juvenile polyarthritis* (Parkhouse 1991). This disease affects five to 11 of every 10 000 children (Andersson-Gäre and Fasth 1992) and appears most frequently during the ages of 2-4 and 8-12 years (Olson et al. 1991). The ratio of girls to boys affected is 3:2. Approximately every second child affected experiences a remission (= no active synovialitis without medication over 2 or more years) within 5-10 years of the beginning of the disease. The frequency of condylar process involvement varies between 29% (Rönning et al. 1974) and 65% (Grosfeld et al. 1973). JCA is divided into a systemic form, a pauciarticular form (affecting a few joints), and a polyarticular form. The effect upon facial morphology is greatest with the latter (Mericle et al. 1996) and least with the systemic form (Hanna et al. 1996).

juvenile chronic arthritis (JCA)

779 Five-year-old girl
The disease first appeared at the age of 3 years. As the panoramic radiograph reveals, only the right joint is affected. The ascending ramus of the affected side is shortened in comparison with the other side. At the time of the examination there was no pain, but the joint capsule and muscles were shortened.

As in adult rheumatoid arthritis, it is mostly the peripheral joints of the hands and feet that are primarily involved.

780 Twenty-two-year-old female patient
Symptoms first appeared at the age of 8 years. During the course of the disease both temporomandibular joints exhibited symptoms. At the age of 22 years grating noises (crepitus) had begun and pain could be elicited in both sides (= compensated capsulitis). In addition, the patient exhibited an anterior open occlusal relationship ("open bite") with only a few contacts on the molars. Because the pains could be provoked during inferior traction, the patient was completely pain-free after elimination of the occlusal vector.

781 Forty-year-old female patient
The deformations of bone in both condylar regions are comparable to the findings shown in Figure 776. However, because the patient first experienced symptoms of rheumatoid arthritis (RA) at the age of 11 years, the correct diagnosis is JCA. In spite of systemic administration of corticosteroids over many years, condylar and mandibular growth was scarcely affected. In this patient too, an anterior open occlusal relationship had developed, but it was corrected with fixed partial dentures.

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Free Bodies within the Joints

Free bodies within the temporomandibular joints have been described long ago by Haller (1764). Anomalous osteochondral bodies are seldom found within the temporomandibular joint, however (Fanibunda et al. 1994). They can appear primarily with synovial chondromatosis or secondarily with osteoarthrosis, intracapsular fractures, osteochondritis dissecans, rheumatic arthritis, avascular necrosis, syphilis, or tuberculosis (Milgram 1977, Olley and Leopard 1978, Norman et al. 1988). The numbers of free joint bodies that occur with synovial chondromatosis (50-100) and osteoarthritis (<10) are quite different (Blenkinsopp 1978, Ikebe et al. 1998). Thirty to forty percent of radiographs of temporomandibular joints in which free bodies are actually present show no radiopacities (Blankestijn et al. 1985, de Bont et al. 1985). Therefore if they are suspected clinically, CT is indicated (Manco and DeLuke 1987, Duvoisin et al. 1990, van Ingen et al. 1990). MRI is also recommended for making the diagnosis (Nokes et al. 1987, Dolan et al. 1989, Holmlund et al. 1992). In this regard, however, artifacts caused by fluid phenomena in the gradient-echo sequence can mimic free bodies (Grabbe et al. 1995).

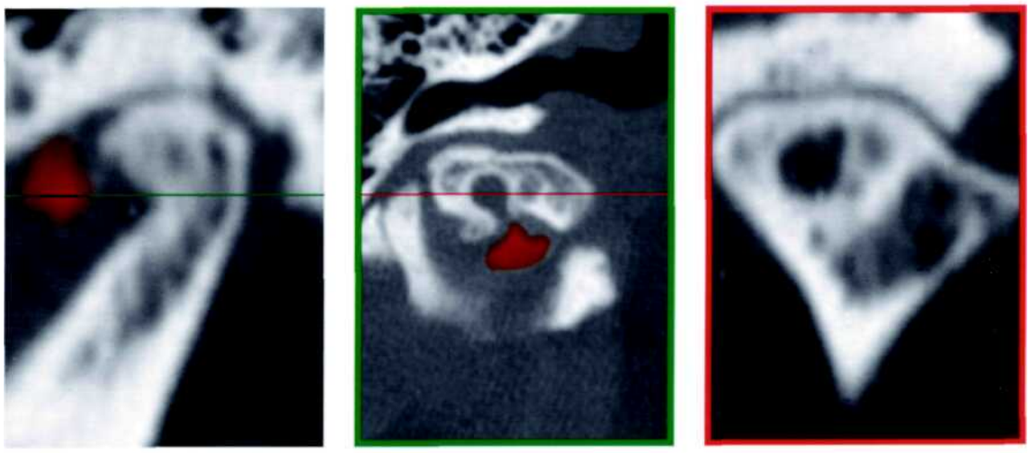
Free bodies in the joints

782 Panoramic radiograph
In this 68-year-old woman there is a degenerative deformation in the left temporomandibular joint with shortening of the condyle. In addition, there appears to be a free body just anterior to the condyle with corresponding clinical symptoms. A CT series is indicated before any surgical intervention. This will also allow verification of the cystic radiolucency within the left condyle.

783 CT of the left temporomandibular joint in three planes
Left: The osteoarthritic deformation of the condyle and the free body (marked red) can be clearly identified in the sagittal section. The green line indicates the axial plane.

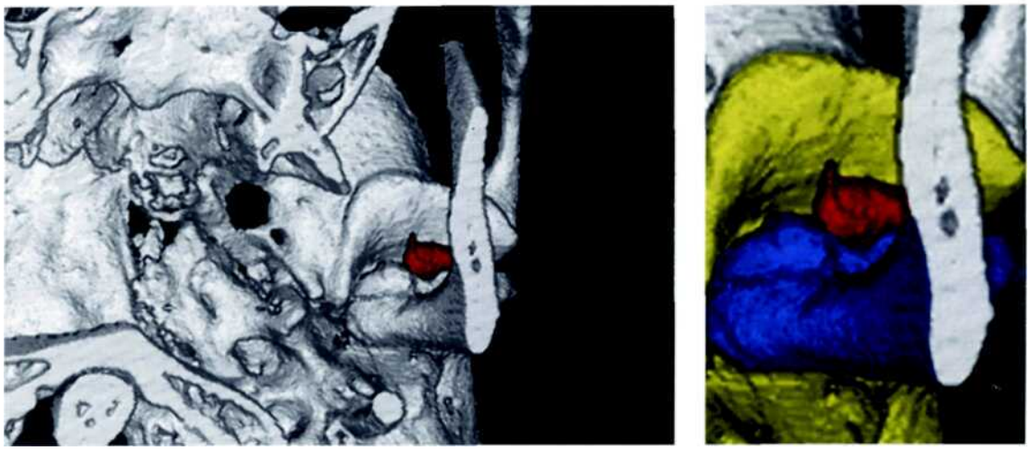
Center: The axial section of the same joint shows the cystic change and the free body (red) as a chip from the condyle. The red line marks the frontal plane.

Right: Cyst formation with deformation of the condyle in the frontal plane.



784 3D-Reconstruction
The spatial reconstruction of the joint from the CT data clarifies the position and size of the free body (marked red) lying anteriorly within the joint. Here, however, all information regarding intraosseous changes is lost.

Right: In this enlarged section, the temporal bone has been colored yellow, the ascending ramus blue, and the free body red. This makes the pathological changes in the joint much easier to visualize.



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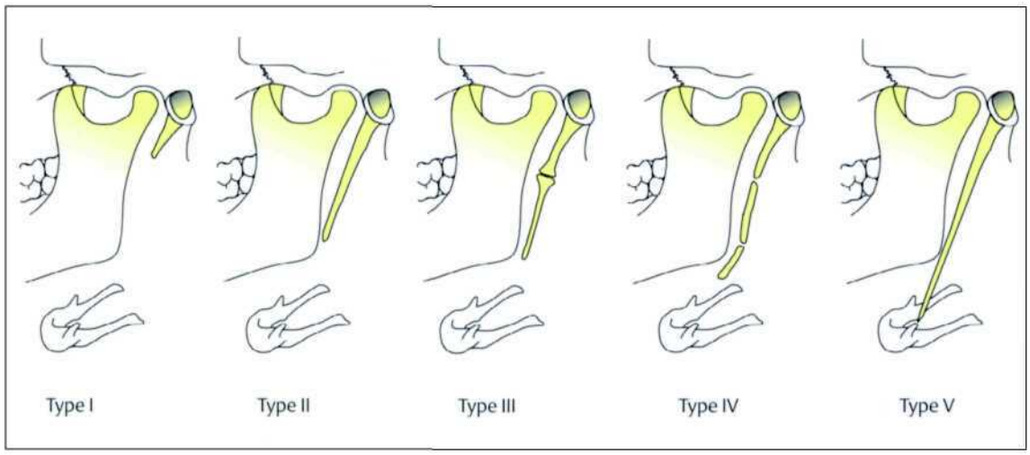
Styloid or Eagle Syndrome

Elongation of the styloid process associated with pain, dysphagia, glossodynia, tinnitus, dizziness, visual disturbances, and syncope has been described as the Eagle syndrome (Eagle 1948, 1949), styloid syndrome (Ettinger and Hanson 1975), and the styloid-stylohyoid syndrome (Gossman and Tarsitano 1977). The normal physiological length of the styloid process is 20-30 mm (Eagle 1937, Langleis et al. 1986). Processes greater than 30 mm in length are referred to as megastyloids. The incidence of these varies from 1.4 to 84.4% (mean = 33%). But only 2-4% of those affected experience symptoms (Zohar et al. 1986, Krennmair et al. 1994). The incidence and length of the ossification increase with age (Ferrario et al. 1990). There is no correlation between the length of the styloid process and the type of clinical symptoms, however (Gossman and Tarsitano 1977, Zaki et al. 1996, DuPont 1998). Three theories seek to clarify the ossification (Camarda et al. 1989): the theory of reactive hyperplasia, the theory of reactive metaplasia, and the theory of anatomical variance. According to recent studies, the theory of anatomical variance appears to come closest to being correct (Krennmair et al. 1994).

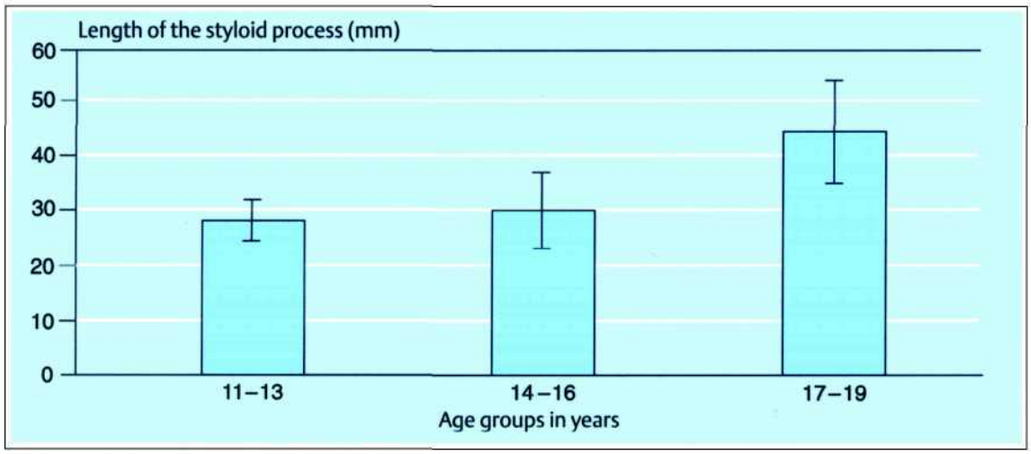
785 Elongated styloid process in a panoramic radiograph
An elongated styloid process (here: Type V) does not necessarily indicate an Eagle syndrome. Only if specific symptoms can be elicited repeatedly during the clinical examination can this be interpreted as evidence of the presence of an Eagle syndrome. The incidence of the Eagle syndrome (or styloid syndrome) is well under 1%. Only a few cases have been described in the literature.



786 Classification of enlarged styloid processes
After Langlaisetal. 1986

Type I normal length
Type II elongation
Type III pseudoarthrosis
Type IV bony chain
Type V complete ossification

Seldom do enlarged styloid processes cause clinical symptoms. When they do, there is an indication for surgery, which may be through an extraoral (Chase et al. 1986, Zohar et al, 1986) or an intraoral (Smith and Cherry 1988) approach. Symptoms are eliminated in 78% of patients operated upon.



787 Further elongation of elongated styloid processes associated with age
Children and adolescents experience increased elongation of the styloid processes with increasing age (Krennmair et al. 1994)
The styloid ligament contains embryonic cartilage cells with the potential for direct ossification, even in adults. Because of this, the styloid process can continue to increase in length even in advanced age (Camarda et al. 1989, Correll et al. 1979).

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Fractures of the Neck and Head of the Condyle

There are two widely separated classifications for fractures of the neck of the condyle. While MacLennan (1969) divided extracapsular fractures into four groups according to the extent of displacement (no displacement, deviation of the fracture line, dislocation, luxation), Spiessl and Schroll (1972) also included intracapsular fractures in their classification.

Condylar fractures make up 19-38% of all mandibular fractures (Ellis et al. 1985, Dimitroulis 1997). The number is even higher in children at 26-60% (Stylogianni et al. 1991). In children less than 6 years of age intracapsular fractures predominate. At the age of 6-15 years 78% of the fractures are in the region of the neck of the condyle, but only 4% are lower neck fractures (Thoren et al. 1997).

Early repositioning seems to be important for the restoration of function (Talwar et al. 1998), although many patients with condylar neck fractures experience little problem over the long term (Choi 1996). Patients who received conservative functional therapy showed no clear advantage over those who were untreated (Kahl-Nieke et al. 1998a).

Classification of condylar neck fractures according to Spiessl and Schroll
Lower neck fractures and fractures with displacement carry a higher risk for the development of functional problems (Türp et al. 1996).

788 Type I and Type II condylar neck fractures
Left: In type I fractures, the neck is fractured but there is virtually no displacement of the fragments.

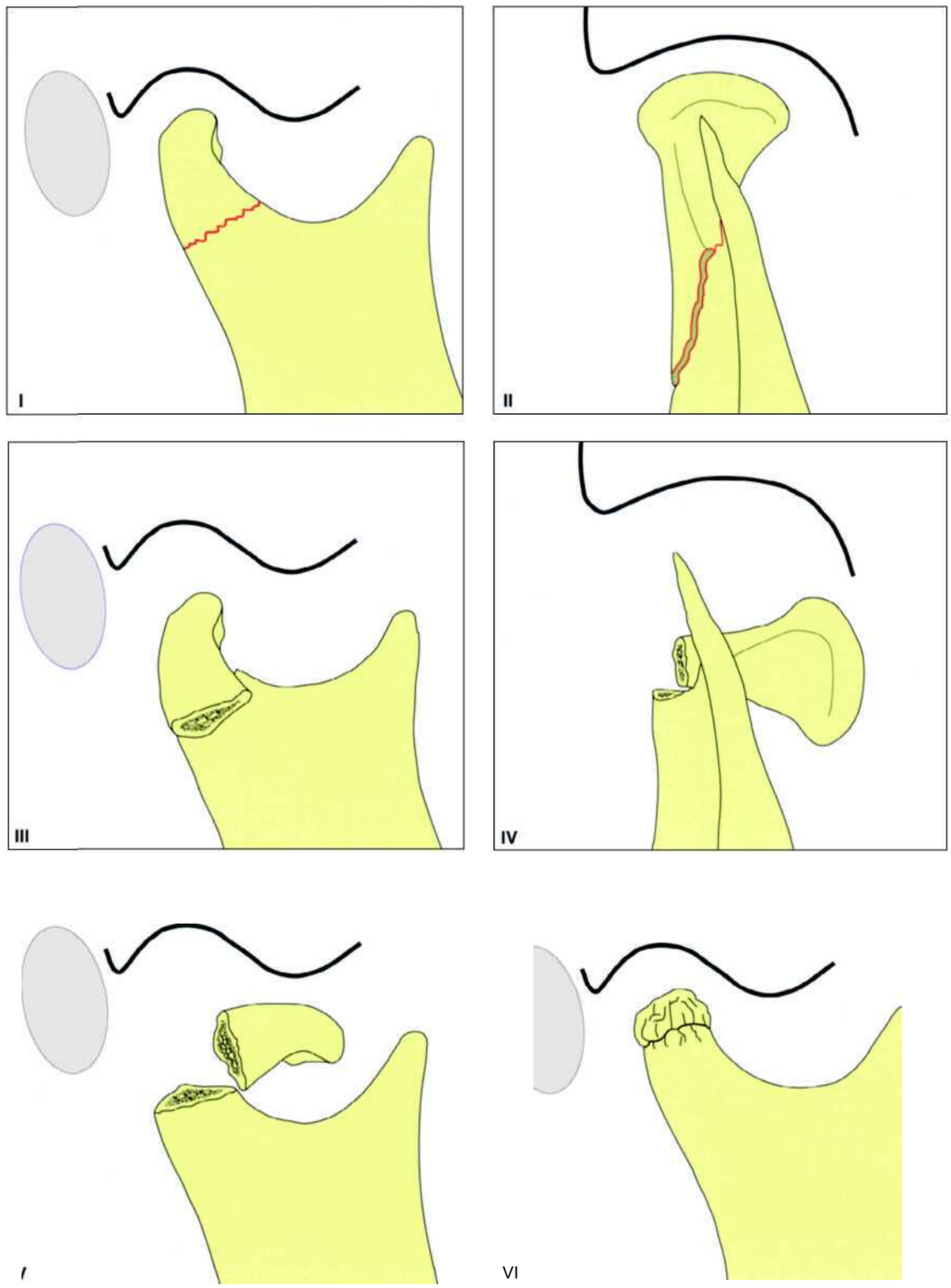
Right: Type II includes lower neck fractures with displacement. Frequently there is still contact between the bony fragments.

789 Type III and Type IV condylar neck fractures
Left: Type III includes fractures high on the neck with anterior, posterior, medial, or lateral displacement. As a rule, there is no contact between the fragments.

Right: Type IV covers lower neck fractures with separation. In this group especially, surgical treatment provides significantly better results than does conservative functional treatment or no treatment at all (Worsaae and Thorn 1994, Widmark 1997).

790 Type V and Type VI condylar neck fractures
Left: Type V includes high neck fractures with displacement. Newer surgical techniques utilize tension screws, resorbable pins, and miniature plates to stabilize the fractured condyle during surgical reduction (Rasse et al. 1991, Silvennoinen et al. 1995, Hachem et al. 1996, Kermer et al. 1998).

Right: Type VI includes fractures of the head of the condyle within the capsule. These occur mostly in children younger than 6 years.



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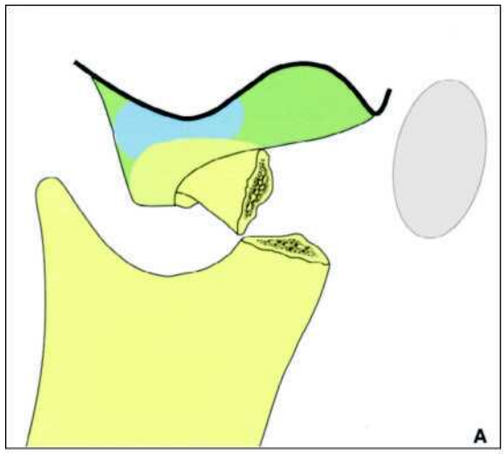
Disk Displacement with Condylar Neck Fractures

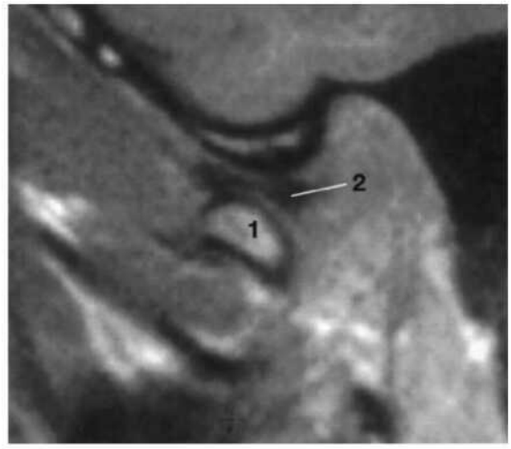
The previously mentioned classification of condylar neck fractures considers only the position of the bone fragments. A more detailed classification distinguishes between displacement types A, B, and C based upon the position of the disk (Bumann et al. 1993):

- *Type A* indicates a displacement of the disk relative to the glenoid fossa. As a rule, it accompanies a condyle dislocated in the sagittal plane (Type I, II, and V according to Spiesel and Schroll). Because the disk can move posteriorly relative to the condyle within a physiological range, the disk-condyle complex is not significantly damaged.

Type B refers to a physiological disk position relative to the fossa with dislocation of the condyle in the frontal plane (Type II and III according to Spiesel and Schroll). The disk-condyle complex is partially damaged.

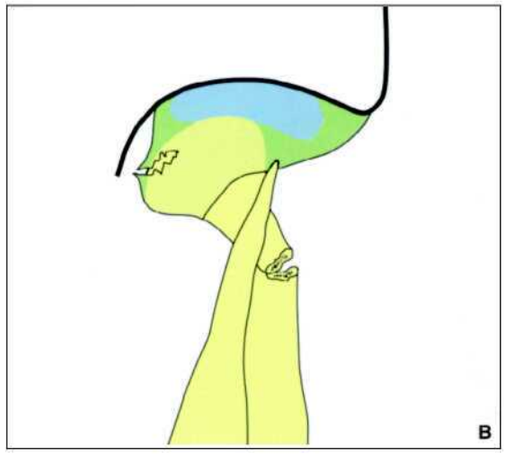
Type C covers total disruption of the disk-condyle complex. The therapeutic importance of this classification system has been confirmed by the findings of other studies (Chuong 1995, Sullivan et al. 1995, Takaku et al. 1996, Choi 1997, Oezmen et al. 1998).

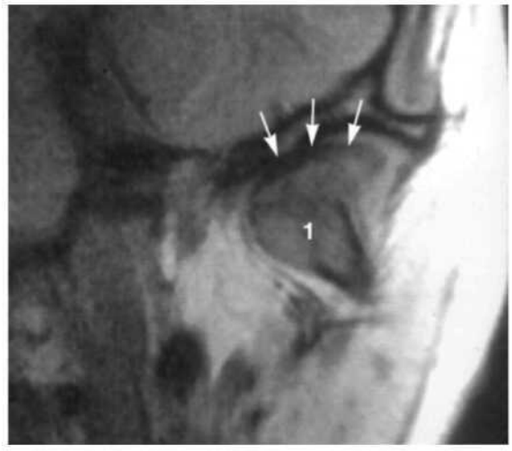




791 Type A: no injury to the disk-condyle complex
Left In spite of extensive dislocation of the condyle in the sagittal plane, the disk-condyle complex is functionally intact. Disk displacements of Type A occur mostly in conjunction with condylar neck fractures of Type I, II, or V.

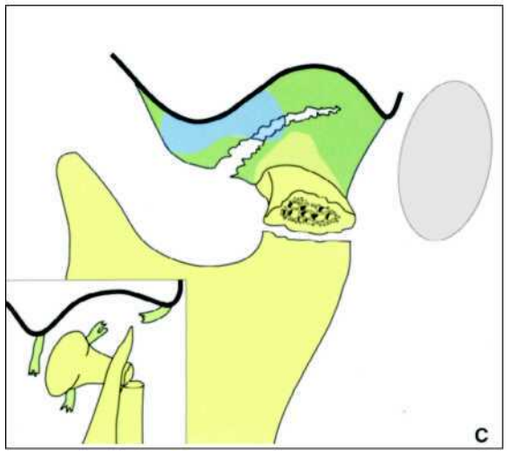
Right: MRI shows displacement of the disk anteriorly relative to the fossa. However, the positional relationship of the disk (1) to the condyle (2) is similar to that found normally with maximal jaw opening.

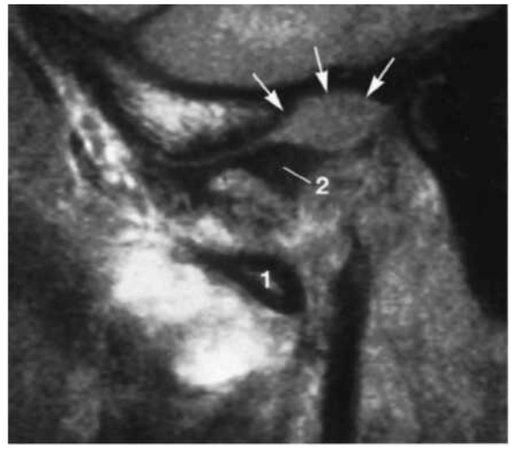




792 Type B: partial disruption of the disk-condyle complex
Left: Due to rotation of the condyle in the frontal plane there is a partial disruption of the disk-condyle complex. Type-B displacement occurs most often with condylar neck fractures of Type II or III with lateral or medial displacement.

Right: MRI shows the rotation of the left condyle (1) medially in the frontal plane. Nevertheless, the disk (arrows) remains in an almost normal position within the fossa.





793 Type C: complete disruption of the disk-condyle complex
Left: The anatomical connection between disk and condyle has been traumatized by the medial displacement of the condyle. Apparently the direction of the damaging force is responsible for keeping the disk on the eminence.

Right: In the MRI the luxated condylar neck is visible in cross-section (1). The disk (2) lies on the eminence and there is an effusion of blood into the upper joint cavity (arrows).

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Fibrosis and Bony Ankylosis

Ankylosis of the temporomandibular joint, which occurs relatively infrequently, can be divided into fibrous and bony ankylosis. The *principle causes* are trauma (fracture/ hemarthrosis), previous joint surgery, infection during childhood, tumors, and a compressive function pattern (Khanna et al. 1981, Chandra and Dave 1985, Dachowski et al. 1990, Faerber et al. 1990, Leighty et al. 1993, Karras et al. 1996). HLA associations (B27) are also discussed (Camilleri et al. 1991, 1992).

With fibrous ankylosis, active movements on the same side are clearly limited, but not painful, and every endfeel is "too hard." Fibrous adhesions occur within the capsule or as fibrosis of the capsule itself. When occurring unilaterally, opening and protruding movements will be deflected toward the affected side. Radiographically there is nothing unusual about the appearance of the bony structures of the joint.

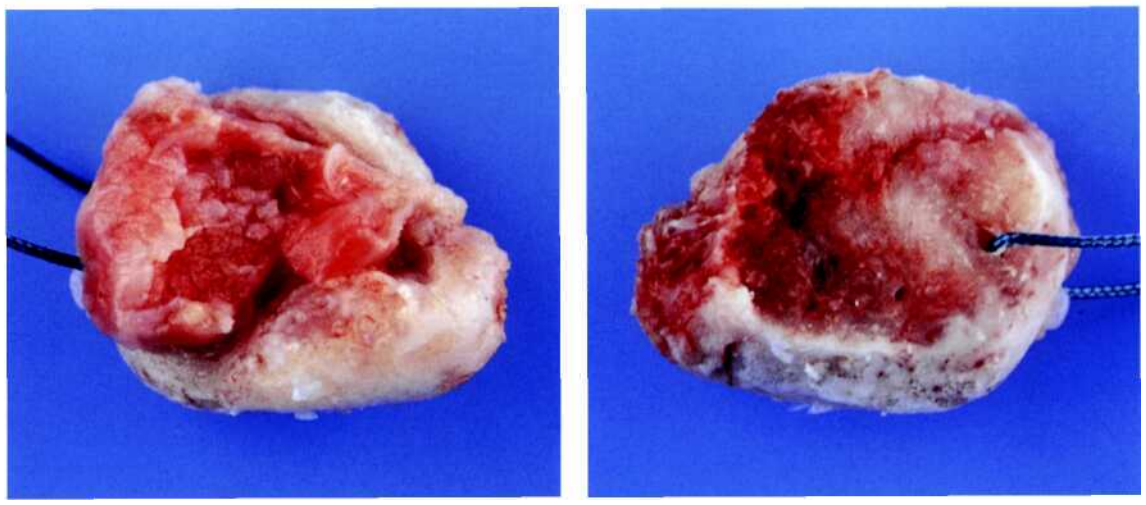
Bony ankyloses greatly restrict active movements, although it is still possible for some patients to open as much as 11 mm. The joint space is no longer visible on the radiograph. Bony ankyloses can be divided into four types, each with its own corresponding therapeutic implications (Sawhney 1986).

794 Fibrous ankylosis
Panoramic radiograph of an 11-year-old boy. Following an episode of otitis media at the age of 2 years, a fibrous ankylosis (arrows) developed on the left side over several years.

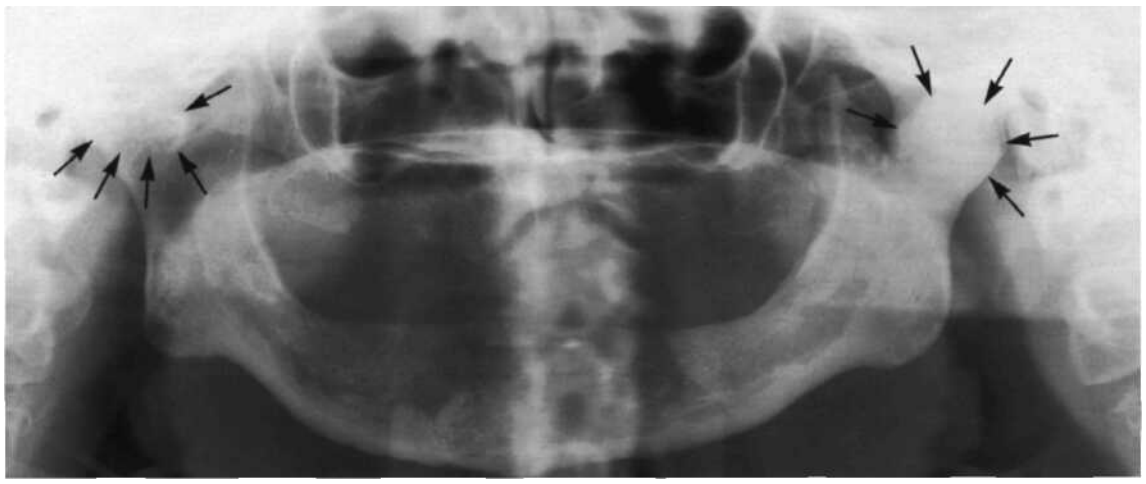
Extensive resection is the treatment of choice (Omura et al.1997). In young patients this should be followed by a costochondral transplant (Posnick and Goldstein 1993). Alternatively, autogenous cartilage, a temporalis muscle flap, or an alloplastic material may be interposed (Brusati et al. 1990, Heggie 1996).

795 Resection of the condyle
Left: Cranial view of the resected left condyle. The extensive central adhesion between the joint surfaces was responsible for the limitation of jaw opening.

Right: Inferior view. The lower the condylectomy is carried out, the less the risk of a recurrence. Surgery must always be followed by specific, systematic physical therapy. If there is a recurrence, laser treatment or a so-called temporomandibular joint implant is indicated (Westermark et al. 1990, MacAfee and Quinn 1992, Moses et al. 1998).



796 Bilateral bony ankylosis
Panoramic radiograph of a 52-year-old woman. No joint spaces can be seen in the regions of the temporomandibular joints. On each side there is a cloudy, indistinctly demarcated shadow (arrows). Thirty-five years ago the patient was kicked by a horse and suffered fractures of both condylar necks. During the phase of consolidation, a deformed condyle often becomes covered by a layer of connective tissue (Flygare et al. 1992). If this does not occur a bony ankylosis may result.



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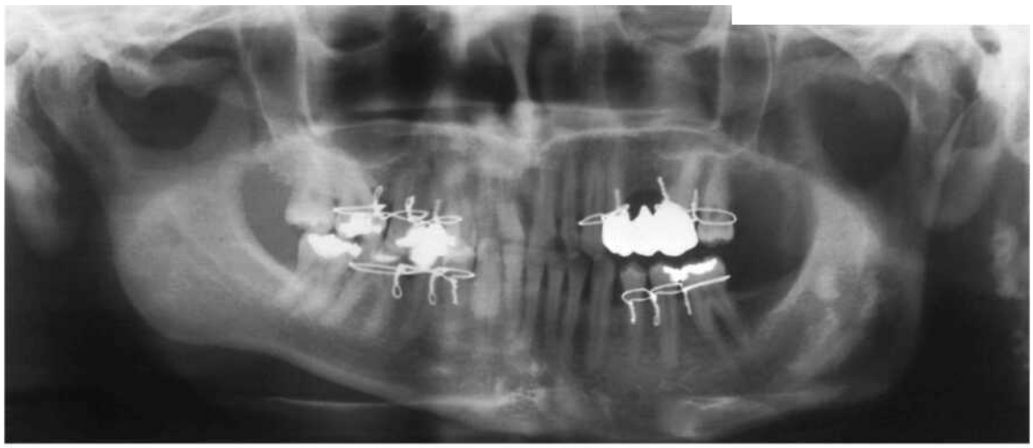
Tumors in the Temporomandibular Joint Region

Tumors rarely occur in the temporomandibular joint region (Allias-Montmayeur et al. 1997). They are divided into primary and secondary tumors, and further classified as benign or malignant as well as metastases.

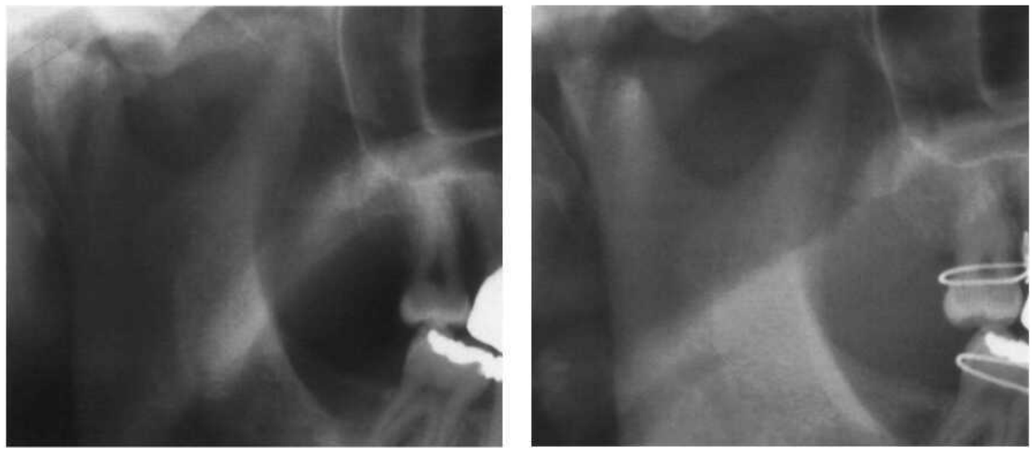
Among the primary *benign* tumors are osteochondromas, osteomas, osteoid osteomas, chondromas, osteoclastomas, eosinophilic granulomas, fibrous dysplasia, myxomas, and ossifying fibromas (Vezeau et al. 1995, Attanasio et al. 1998). Some *primary malignant* tumors are fibrosarcomas, chondrosarcomas, osteochondrosarcomas, synovial cell sarcomas, and osteosarcomas (Sesenna et al. 1997, Gobetti and Turpl998). *Secondary benign* tumors are represented by cholesteatomas, neurofibromas, and basaliomas, whereas *secondary malignant* tumors are frequently found to be adenocarcinomas, maxillary sinus carcinomas, squamous cell carcinomas, cylindromas, and ameloblastomas.

The rare metastases are usually related to a carcinoma of the breast (Stravropoulos and Ord 1993), bronchi (Rutsatz et al. 1990) or lungs (Glaser et al. 1997), or to a malignant melanoma (Nortje et al. 1996), colorectal carcinoma (Balestreri et al. 1997), or squamous cell carcinoma (Catone and Carlson 1990).



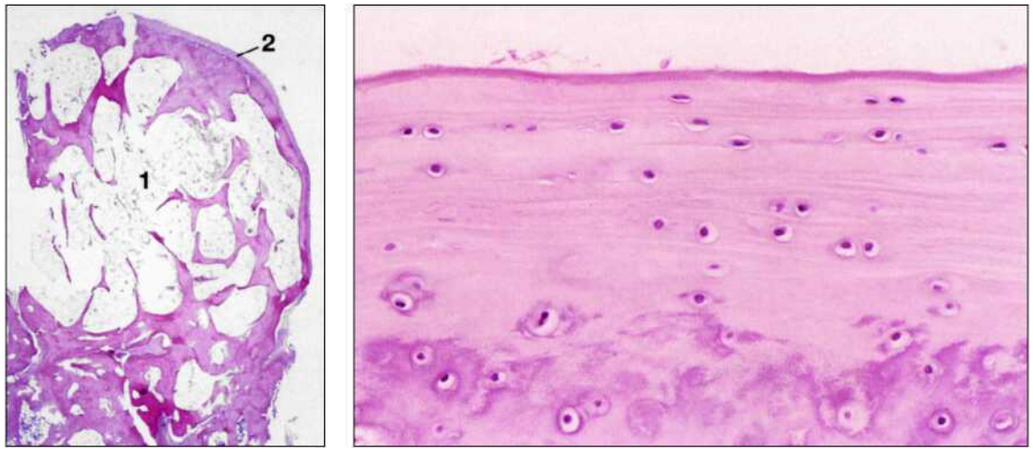
Osteochondroma on the left side

797 Preoperative condition
Osteochondromas are the most common tumors of the temporomandibular joints. In this 27-year-old woman the tumor has caused the left condylar process to be elongated with irregular borders. The elongation has led to a lateral open occlusal relationship. Diagnosis is made more difficult by the presence of a hyperplastic condyle on the right side, which has caused a midline deviation to the left. This directed attention to the right joint.



798 Postoperative condition
A section of the panoramic radiograph made on the first day after surgery. A condylectomy was performed removing the osteochondroma down to sound bone. The left side is stabilized statically by the teeth that are now in occlusion and dynamically by the musculature.

Left: Two years later the condyle has become slightly remodeled through progressive adaptation. The shadow just anterior to the condyle indicates a free body in the joint.



799 Histological preparation
Magnified section of the condylar surface covered with hyaline cartilage. There is an unusually large number of chondrocytes visible compared with normal fibrous cartilage. In the deeper layers the hyaline cartilage is replaced by vesicular cartilage and a zone of enchondral ossification.

Left: Wider view of the resection. The surface is made up of fibrous tissue (**1**) in some areas and hyaline cartilage (2) in others.

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Joint Disorders—Articular Surfaces (International Classification of Diseases, 9th Rev.)

Diagnosis	Deformation of the articular surfaces	Osteoarthrosis
ICDA Number	ICD.9.CM 524.69	ICD.9.CM 715.38
Definition	Cartilaginous and/or osseous changes in temporal or condylar joint surfaces through adaptation to functional loading of the joint structures	Primary or secondary noninflammatory degenerative condition of a joint with structural changes in joint surfaces
Loading vector	Superior and/or anterosuperior	Superior and/or anterosuperior
Symptoms	—Painless, no limitation of active movements, often no joint sounds —Occasionally causes clicking of low intensity with no deviation of mandible	—Painless, occasionally active movement is limited —Grating sounds (crepitus) of varying intensity
Clinical diagnostic signs	—Detectable clinically either not at all or only through dynamic compression and medial and lateral translation —Dynamic compression produces sounds in same place as active movements, but somewhat louder and more palpable. Sounds are not intensified by translation	—No provocable pain in temporomandibular joints —Palpation of crepitus directly on condyle or angle of the jaw —Increased crepitus under dynamic compression —Closer localization of degenerated joint areas through medial and lateral translation
Instrumental diagnostic aids	—Mechanical or electronic axiography for documentation —Occlusal analysis on articulator is not definitive for diagnosis	—Mechanical or electronic axiography in pronounced cases for documentation —Occlusal analysis on articulator, not definitive for diagnosis
Imaging diagnostic aids	—Conventional tomography, CT, and MRI may provide information if subchondral bone is deformed. Severe cases may even be visible in a panoramic radiograph —Cartilaginous changes are seen only in MRI or MR microscope, but these are not indicated	—May be evident on panoramic radiogrph in advanced stages —CT and MRI are indicated only if surgical treatment is planned
Treatment direction	None	Inferior
Impediments in treatment direction	—Hypertonicity, hypertrophy, or shortening of jaw-closing muscles —Constriction of joint capsule	—Hypertonicity, hypertrophy, or shortening of jaw-closing muscles —Constriction of joint capsule
Therapy	—No medical indication for therapy	According to degree of severity and capsule mobility: —No therapy —Relaxation therapy, or —Decompression therapy

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Osteoarthritis	Bony ankylosis	Diagnosis
ICD.9.CM 716.88 or 716.98	ICD.9.CM 524.61 (fibrous or osseous)	**ICDA Number**
Inflammatory degenerative changes in cartilaginous and osseous joint surfaces	Growing together of the bones at joint surfaces with extreme restriction of mandibular movement	**Definition**
Superior and/or anterosuperior	Superior and/or anterosuperior	**Loading vector**
—Pain and crepitus —Limitation of active movements	—Extreme restriction of mandibular movement with no pain in affected joint —In spite of bony fusion, unilateral ankylosis can permit a mouth opening of up to approximately 11 mm.	**Symptoms**
—Pain and crepitus evoked by dynamic compression —Dynamic translation with compression permits more precise localization	—History of a traumatic inflammatory origin and gradual development over the years —Limitation of mouth opening —No palpable condyle movement	**Clinical diagnostic signs**
—Mechanical or electronic axiography in pronounced cases for documentation —Occlusal analysis on articulator, not definitive for diagnosis	—Axiography for documentation of restricted translation (caution: projection phenomenon) —Occlusal analysis on articulator, not definitive for diagnosis	**Instrumental diagnostic aids**
—Radiographic findings as with osteoarthrosis —MRI with T1 and T2 weighting to reveal inflammatory effusion of fluid	—Panoramic radiograph shows a diffuse, cloudy shadow in joint region —Presurgical 3D CT to evaluate the extent of the ankylosis in 3 dimensions	**Imaging diagnostic aids**
Inferior	Inferior	**Treatment direction**
—Hypertonicity, hypertrophy, or shortening of jaw-closing muscles —Constriction of joint capsule	—Ossification —Hypertonicity, hypertrophy, and shortening of jaw-closing muscles as well as constriction of joint capsule	**Impediments in treatment direction**
According to degree of severity and capsule mobility: —Relaxation therapy —Decompression therapy —Arthroscopic lavage	—Surgery with an upper or lower condylectomy and insertion of an autogenous or allogenic meniscus —Systematic perioperative physical therapy	**Therapy**

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Joint Disorders—Articular Disk

Diagnosis	Disk deformation	Disk perforation
ICDA Number	ICD.9.CM 524.63 (nonspecific)	ICD.9.CM 524.63 (nonspecific)
Definition	Reversible or irreversible disk deformation as a sign of progressive or regressive adaptation on the disk	Interruption of continuity of articular disk
Loading vector	Superior and/or posterosuperior	Anterosuperior and/or superior
Symptoms	As a rule, no clinical symptoms. Occasionally a clicking sound is detected	—With progressive adaptation, no clinical symptoms —With regressive adaptation (osteoarthrosis/osteoarthritis), variable clinical manifestations (crepitus, clicking, pain)
Clinical diagnostic signs	Cannot be diagnosed clinically	Cannot be reliably diagnosed clinically
Instrumental diagnostic aids	Cannot be diagnosed with instruments	Cannot be reliably diagnosed with instruments
Imaging diagnostic aids	—Not detectable on conventional radiographs —Disk deformation cannot be deduced from configuration of the joint space —CT (with soft-tissue window) permits limited evaluation of disk's shape —MRI, T1- and T2-weighted, is the method of choice	—Not detected on conventional radiographs —Arthrography is not indicated because of invasiveness and radiation exposure —MRI permits radiation-free visualization of disk perforations in 70% of cases
Treatment direction	Sometimes inferior, anteroinferior	Inferior
Impediments in treatment direction	—Hypertonicity, hypertrophy (= increased muscle strength), or shortening of jaw-closing muscles —Constriction of joint capsule	—Hypertonicity, hypertrophy (= increased muscle strength) and shortening of jaw-closing muscles —Constriction of joint capsule
Therapy	—As a rule, no treatment is necessary except in combination with disk displacement and capsulitis	According to degree of severity and capsule mobility: —Relaxation therapy —Decompression therapy —Arthroscopic lavage

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Joint Disorders—Bilaminar Zone and Joint Capsule

Disk hypermobility	Partial disk displacement with reposition	Diagnosis
ICD.9.CM 524.63 (nonspecific)	ICD.9.CM 524.63 (nonspecific)	ICDA Number
—Initial stage of anterior disk displacement relative to condyle, with repositioning during mouth opening —Disk displacement begins in lateral or medial part of joint	Partial displacement of articular disk relative to the condyle with repositioning during mouth opening. Displacement of disk in lateral or medial part of joint	Definition
Posterolateral or posteromedial	Posterolateral or posteromedial	Loading vector
—Initial clicking sound during excursive movement (jaw opening, protrusion, mediotrusion) —Appearance and intensity of clicking depends on muscle tone and current associated condylar position	—Reciprocating clicks during excursive and incursive movements (opening/closing, protrusion/mediotrusion/retrusion) —Initial or intermediate click during excursion, terminal click during return	Symptoms
—Reduction of intensity of the sound on same side under dynamic compression —An associated dynamic translation increases the sound —During additional compression the sound is further increased	—Under dynamic compression the clicks are louder and later compared with unmanipulated active movement —Sometimes the clicks are excluded with simultaneous limitation of movement (nonreducing disk displacement) —During dynamic lateral and medial translations, no sounds in one direction and a louder sound in the other	Clinical diagnostic signs
—Diagnosis by axiographic tracings of active movements is not dependable because only half of such tracings provide evidence of disk displacement —Axiographic tracings in combination with manual dynamic test methods for documentation	—Diagnosis by axiographic tracings of active movements is not dependable because only half of such tracings provide evidence of disk displacement —Axiographic tracings in combination with manual dynamic test methods for documentation	Instrumental diagnostic aids
—Not revealed by conventional radiographs —CT not indicated because of radiation exposure —MRI is the imaging method of choice (T1-weighted images in habitual occlusion and T2-weighted images at maximal jaw opening are needed in at least 3 planes)	—Not revealed by conventional radiographs —CT not indicated because of radiation exposure —MRI is the imaging method of choice (T1-weighted images in habitual occlusion and T2-weighted images at maximal jaw opening are needed in at least 3 planes)	Imaging diagnostic aids
Sometimes anteromedial or anterolateral	Anteromedial or anterolateral	Treatment direction
—Disrupted innervation or reduced strength of lateral pterygoid muscle —Hypertonicity or shortening of retracting muscles —Sagittal constriction of joint capsule	—Disrupted innervation or reduced strength of lateral pterygoid muscle —Hypertonicity or shortening of retracting muscles —Sagittal constriction of joint capsule	Impediments in treatment direction
—No treatment if structures are fully adapted —Repositioning splint or orthodontic appliance —Physical therapy to eliminate the musculoskeletal impediments through specific mobilization and relaxation techniques plus isometric and isotonic exercises	—No treatment if structures are fully adapted —Repositioning splint or orthodontic appliance —Physical therapy to eliminate the musculoskeletal impediments through specific mobilization and relaxation techniques plus isometric and isotonic exercises	Therapy

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Diagnosis	Partial disk displacement without repositioning or partial repositioning	Total disk displacement with repositioning
ICDA Number	ICD.9.CM 524.63 (nonspecific)	ICD.9.CM 524.63 (nonspecific)
Definition	Partial displacement of articular disk relative to the condyle with no repositioning or only partial repositioning during excursive movements (jaw opening, protrusion, mediotrusion)	Complete displacement of articular disk relative to the condyle with repositioning during excursive movements (jaw opening, protrusion, mediotrusion)
Loading vector	Posterolateral or posteromedial	Posterior or posterosuperior
Symptoms	—Very variable clinical symptoms —In spite of lack of repositioning, half of these patients have a click during excursive movements (partial repositioning of disk) —Not necessarily accompanied by limited jaw opening	—Reproducible initial, intermediate, or terminal click during excursive movements (jaw opening, protrusion, mediotrusion) and usually a terminal click during return movements
Clinical diagnostic signs	—Any clicking during active movements can be avoided through dynamic translation laterally or medially (manipulated jaw opening is not restricted) —If circumstances permit, failure of the disk to reposition is confirmed by a rebounding endfeel during painless passive jaw opening	—Under dynamic compression the click is later and louder —With dynamic lateral and medial translations the sound persists with varying intensity —Auscultation cannot distinguish between partial and total disk displacement
Instrumental diagnostic aids	—Diagnosis by axiographic tracings of active movements is not dependable because only half of the tracings provide evidence of disk displacement —Axiographic tracings in combination with manual dynamic test methods for documentation	—Diagnosis by axiographic tracings of active movements is not dependable because only half of the tracings provide evidence of disk displacement —Axiographic tracings in combination with manual dynamic test methods for documentation
Imaging diagnostic aids	—Not revealed by conventional radiographs —CT not indicated because of radiation exposure —MRI is the imaging method of choice (T1-weighted images in habitual occlusion and T2-weighted images at maximal jaw opening are needed in at least 3 planes)	—Not revealed by conventional radiographs —CT not indicated because of radiation exposure —MRI is the imaging method of choice (T1-weighted images in habitual occlusion and T2-weighted images at maximal jaw opening are needed in at least 3 planes)
Treatment direction	Anterior or inferior	Anterior or anteroinferior
Impediments in treatment direction	—Hypertonicity, hypertrophy (=increased muscle strength), and shortening of jaw-closing muscles —Sagittal and vertical constriction of joint capsule	—Disrupted innervation or reduced strength of lateral pterygoid muscle —Hypertonicity or shortening of retracting muscles —Sagittal constriction of joint capsule
Therapy	—Attempt to recapture and stabilize disk with repositioning splint or orthodontic appliance —Alternatively, relief of pressure on bilaminar zone through decompression therapy —Physical therapy to eliminate musculoskeletal impediments through specific mobilization and relaxation techniques plus isometric and isotonic exercises	—Structural conditions are unfavorable for long-term success of conservative therapy —Initial therapy with repositioning splint or orthodontic appliance depending on given condition —Physical therapy to eliminate musculoskeletal impediments through specific mobilization and relaxation techniques plus isometric and isotonic exercises

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Total disk displacement without repositioning	Disk displacement with adhesion	Diagnosis
ICD.9.CM 524.63 (nonspecific)	ICD.9.CM 524.63 (nonspecific)	**ICDA Number**
Complete displacement of articular disk relative to the condyle with no repositioning during excursive movements (jaw opening, protrusion, mediotrusion)	Partial or total disk displacement with reduced sagittal mobility of disk due to connective tissue (= limited translation of disk)	**Definition**
Posterior or posterosuperior	Posterolateral, posterosuperolateral, posterior, posterosuperior	**Loading vector**
–Acute and decompensated stage: pain in affected joint, severely limited jaw opening with deflection to the affected side, limited protrusion and mediotrusion to the affected side –Adapted stage: jaw opening in normal range, no pain and no deflection (one-third of all patients with nonreducing disk displacement) –Rebounding endfeel when there is painless limitation of jaw opening	–Initial to intermediate click during excursive movements –Intermediate to terminal click during return movements –Clicking occurs with or without pain –Usually no limitation of jaw opening because limited translation of the condyle has been compensated for by increased mobility in lower joint cavity	**Symptoms**
–Specific history by patient –Rebounding endfeel with painless passive jaw opening –Pain from passive superior compressions –No clicking during excursive movements	–Louder sound from same place during excursive dynamic compression –During dynamic lateral and medial translations the clicking sometimes persists (= total displacement) or may disappear in one direction (= partial displacement)	**Clinical diagnostic signs**
–Axiographic tracings in combination with manual dynamic test methods are essentially only for documentation –Occlusal analysis on an articulator is diagnostically irrelevant	–Axiographic tracings in combination with manual dynamic test methods are essentially only for documentation –Occlusal analysis on an articulator is diagnostically irrelevant	**Instrumental diagnostic aids**
–Not revealed by conventional radiographs –CT not indicated because of radiation exposure –MRI is the imaging method of choice (3 discrete layers): • T1-weighted images in habitual occlusion • T2-weighted images at maximal jaw opening • T1-weighted in angled coronal plane –Although the diagnosis is confirmed by MRI, clicks may occur clinically at times (folding of disk)	–Not revealed by conventional radiographs –CT not indicated because of radiation exposure –MRI is the imaging method of choice (3 discrete layers): • T1-weighted images in habitual occlusion • T2-weighted images at maximal jaw opening • T1-weighted in repositioned position	**Imaging diagnostic aids**
Anterior, anteroinferior, or inferior	Anterior, anteroinferior, or anteromedial	**Treatment direction**
–Hypertonicity, hypertrophy (= increased muscle strength), and shortening of jaw-closing muscles –Sagittal and vertical constriction of joint capsule	–Disrupted innervation or reduced strength of lateral pterygoid muscle –Hypertonicity or shortening of retracting muscles –Sagittal constriction of joint capsule	**Impediments in treatment direction**
–Attempt to recapture and stabilize disk with repositioning splint or orthodontic appliance –Decompression treatment to relieve pressure on bilaminar zone –Elimination of musculoskeletal impediments –Diskectomy if symptoms persist and patient's suffering is great	–Adhesions cannot be resolved by dental treatment –For relief of pain, insertion of a decompression splint, repositioning splint, or orthodontic appliance –Elimination of musculoskeletal impediments –Arthroscopic procedures to loosen adhesions are seldom indicated	**Therapy**

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Diagnosis	Posterior disk displacement	Disk displacement during eccentric mandibular movement
ICDA Number	ICD.9.CM 524.63 (nonspecific)	ICD.9.CM 524.63 (nonspecific)
Definition	Partial or total displacement of articular disk posteriorly at habitual occlusion and maximal jaw opening	Displacement of a disk that occupies a physiological position in habitual occlusion but is displaced distally during mandibular movement and loses its functional contact with the joint surfaces
Loading vector	Anterior or anteroinferior	Anterior or anteroinferior
Symptoms	—Jaw closure is difficult in terminal phase —No clicking sounds —Occasional pain during return movements —No limitation of active movements	—Terminal click during excursive mandibular movements (opening, protrusion, mediotrusion) —Intermediate to terminal click during return movements (closing, retrusion, laterotrusion)
Clinical diagnostic signs	—Specific patient history (trauma) —No specific manual examination techniques are available to provide a reliable differential diagnosis	—Clinical diagnostic methods provide no reliable results —In some cases, excursive click is amplified by dynamic compression —Progressive compression during incursive movements can prevent clicking and impede jaw closure
Instrumental diagnostic aids	—Reliability of axiographic tracings is questionable because of insufficient reports in the literature —Occlusal analysis on an articulator is diagnostically irrelevant	—Lateral and medial deviations of pathways on axiographic or pantographic tracings are not clinically significant as indicators of disk displacement during excursive jaw movements —Occlusal analysis on an articulator is diagnostically irrelevant
Imaging diagnostic aids	—Not revealed by conventional radiographs —CT not indicated because of radiation exposure —MRI is the imaging method of choice (3 discrete layers): • T1-weighted images in habitual occlusion • T2-weighted at maximal jaw opening • T1-weighted in corrected coronal plane	—Not revealed by conventional radiographs —CT not indicated because of radiation exposure —MRI is the imaging method of choice (3 discrete layers): • T1-weighted images in habitual occlusion • T2-weighted images at maximal jaw opening • T1-weighted in corrected coronal plane
Treatment direction	None	None
Impediments in treatment direction	None	None
Therapy	—No treatment if there are no symptoms —Decompression if there are symptoms —Diskectomy if symptoms are persistent and severe	—No treatment if there are no symptoms —With symptoms, physical therapy or arthroscopic mobilization of disk if disk displacement is the result of limited translation of disk (= adhesion)

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Perforation of bilaminar zone	Static joint compression	Diagnosis
ICD.9.CM 524.63 (nonspecific)	Not classified	**ICDA Number**
Interrupted continuity of bilaminar zone	Superior, posterosuperior, or posterior displacement of condyle due to a corresponding static occlusal vector (= discrepancy between centric and habitual occlusion) without constriction of joint capsule	**Definition**
Superior or posterosuperior	Superior, posterosuperior, or posterior	**Loading vector**
—In some cases totally asymptomatic, but may be associated with severe pain (capsulitis, synovialitis)	—Asymptomatic if bilaminar zone is well adapted —Pain in joint region if adaptation of bilaminar zone is regressing	**Symptoms**
Perforation cannot be diagnosed clinically	—Reproducible pain from passive compression —Normal (hard ligamentary) endfeel with traction and anterior translation —Presence of superior, posterosuperior, or posterior static occlusal vector	**Clinical diagnostic signs**
Not detectable with instruments	—Static occlusal vector in instrumental occlusal analysis (e.g. MPI), or detectable by paraocclusal electronic axiography —Loading vector and capsule mobility (endfeel) cannot be determined by instruments	**Instrumental diagnostic aids**
—Cannot be diagnosed with conventional radiographs —Arthrography contraindicated because of invasiveness, radiation exposure, and lack of any therapeutic benefit —Approximately 70% of perforations in bilaminar zone can be correctly identified by MRI	Not indicated: —Condylar position cannot be reliably evaluated in panoramic radiograph or Schüller projection —Conventional tomography, CT, and MRI can show the actual condyle—fossa relationship, but they permit no conclusions regarding adaptation of bilaminar zone, capsule mobility, or any occlusal vectors present	**Imaging diagnostic aids**
Inferior or anteroinferior	If indicated, inferior, anteroinferior, or anterior	**Treatment direction**
—Hypertonicity, hypertrophy (= increased muscle strength), and shortening of jaw-closing muscles —Anterior-posterior and vertical constriction of joint capsule	No musculoskeletal impediments	**Impediments in treatment direction**
—Arthroscopy for therapeutic lavage —If pain symptoms persist, diskectomy is indicated	—No pressing need for treatment if structures are well adapted —Fabrication of a relaxation splint to compensate for occlusal discrepancies —Following preliminary therapy, creation of a stable centric occlusion	**Therapy**

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Diagnosis	Functional capsule hypomobility	Fibrous ankylosis
ICDA Number	ICD.9.CM 524.69	ICD.9.CM 524.61
Definition	Superior, posterosuperior, or posterior displacement of condyle with constriction of joint capsule	Limited mandibular movement because of a generalized, usually trauma-induced, retraction of joint capsule with binding of joint surfaces by connective tissue
Loading vector	Superior, posterosuperior, or posterior	Superior, posterosuperior, or posterior
Symptoms	–Asymptomatic if bilaminar zone is well adapted –Pain in joint region if adaptation of bilaminar zone is regressing (capsulitis)	–Severe restriction of all active mandibular movements –In unilateral cases, marked deviation toward the affected side –No pain if bilaminar zone is well adapted –If bilaminar zone is poorly adapted, there may be pain in joint regions (capsulitis)
Clinical diagnostic signs	–In the regressive stage, reproducible pain from passive compression –A "too hard" endfeel with traction or anterior translation –Demonstration of superior, posterosuperior, or posterior contributing factors	–In the regressive stage, reproducible pain from passive compression –A "too hard" endfeel with traction and all translations –Usually no discrepancy between centric and habitual occlusion (static occlusal vector) because of generalized constriction of joint capsule
Instrumental diagnostic aids	–Occlusal analysis on an articulator and paraocclusal electronic axiography are only conditionally useful in diagnosing advanced capsule hypomobility –Axiographic tracings in combination with passive compressions are useful predominantly for documentation	–Occlusal analysis on an articulator and paraocclusal electronic axiography are only conditionally useful in diagnosing advanced capsule hypomobility. –Axiographic tracings in combination with passive compressions are useful predominantly for documentation (very short movement pathways)
Imaging diagnostic aids	Not indicated: –Condylar position cannot be reliably evaluated in panoramic radiograph or Schüller projection –Conventional tomography, CT, and MRI can show the actual condyle–fossa relationship, but they permit no conclusions regarding adaptation of bilaminar zone, capsule mobility, or any occlusal vectors present	–Conventional radiographs are nondiagnostic –CT provides no additional information –MRI is indicated only to exclude a nonreducing disk displacement: • T1-weighted images in habitual occlusion • T2-weighted images at maximal jaw opening • T1-weighted in corrected coronal plane
Treatment direction	Inferior, anteroinferior, or anterior	Inferior, anteroinferior, anterior, medial, and lateral
Impediments in treatment direction	The functional capsule hypomobility itself is the musculoskeletal impediment	The fibrous ankylosis itself is the musculoskeletal impediment
Therapy	–Decompression splint at present nonmanipulated centric –Mobilization of joint capsule through physical therapy –Adjustment following each physical therapy session –After successful mobilization, creation of a final stable occlusion	–Decompression splint at present nonmanipulated centric, mobilization of joint capsule in all directions through physical therapy, adjustment of splint after every physical-therapy session –Adjustment following each physical-therapy session –After successful mobilization, creation of a final stable occlusion –Alternatively, surgery (condylectomy)

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Sclerosing of lateral ligament	Capsulitis with specific loading vector (localized capsulitis)	Diagnosis
ICD.9.CM 848.1 (nonspecific)	ICD.9.CM 524.62 (nonspecific) (inflammatory process)	ICDA Number
Hardening of the lateral capsular ligament following trauma or functional overloading. In rare cases the medial ligament may also be affected	Localized changes in joint capsule or bilaminar zone	Definition
Inferior, lateral (from trauma)	Varies from case to case	Loading vector
—Initial or intermediate click during excursive mandibular movements (opening, protrusion, mediotrusion) due to sclerosis of the ligament, apposition of bone on lateral pole of the condyle, or increased tension in lateral ligament —Intermediate or terminal click during incursive movements	Continuous or recurrent pain in joint region, radiating in different directions	Symptoms
—Medial translation reduces intensity of the click —The click becomes louder during lateral translation, but if compression is added, it becomes softer again —Alternatively, palpation of the lateral ligament after previous lateral translation will reduce the click —Palpation of a firm cord at lateral pole of the condyle, sometimes painful	Reproducible elicitation of pain during joint manipulation (passive compression, traction, and translation) in up to 3 specific directions	Clinical diagnostic signs
—Axiographic tracings of active movements produce no pathway markings characteristic of clicking phenomena in lateral region of the joint capsule	Paraocclusal electronic axiography and instrumented occlusal analysis in combination with passive compression to serve for documentation	Instrumental diagnostic aids
—Cannot be diagnosed on radiographs. —MRI indicated only to exclude reducing disk displacement: • T1-weighted images in habitual occlusion • T2-weighted images at maximal jaw opening • T1-weighted in therapeutic (click-free) mandibular position in sagittal plane	—Cannot be diagnosed on radiographs —MRI indicated only when a nonreducing disk displacement is suspected: • T1-weighted images in habitual occlusion • T2-weighted images at maximal jaw opening • T1-weighted in corrected coronal plane	Imaging diagnostic aids
Superior, if any	Opposite to direction of individual loading vector	Treatment direction
—Disrupted innervation or weakening of lateral pterygoid muscle —Disrupted innervation or weakening of masseter muscles —Premature centric contacts in molar region —Premature nonworking side contacts during mesiotrusion (hyperbalance)	—Disrupted innervation or weakening of lateral pterygoid muscle —Hypertonicity or shortening of elevator and/or retractor muscles —Sagittal or vertical constriction of articular capsule	Impediments in treatment direction
No urgent need for treatment, but if occasion arises: —Transverse rubbing of lateral ligament as physical therapy —Removal of all occlusal interferences —Relaxation of suprahyoid muscles —Coordination of disrupted movement pathways	—Elimination of musculoskeletal impediments —Elimination of occlusion-caused portions of overall loading vector by means of a relaxation splint fabricated at the nonmanipulated neurophysiological centric —Definitive restoration of a stable occlusion —Anti-inflammatory medication p.r.n.	Therapy

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Diagnosis	Acute capsulitis (capsulitis with unspecified loading vector)	Synovialitis
ICDA Number	ICD.9.CM 524.62 (nonspecific)	ICD.9.CM 524.62 (nonspecific)
Definition	Generalized painful inflammation of capsule and/or bilaminar zone caused by dysfunction or trauma	Inflammation of synovial membrane with increased production of synovial fluid with acute capsulitis
Loading vector	Nonspecific (pain increases with loading in any direction)	Specific or nonspecific
Symptoms	–Localized pain at rest –Increased pain with active movements –Usually extreme limitation of movement –When unilateral, mandible deviates to affected side	–Localized pain at rest –Increased pain with active movements, especially during jaw closure –Limitation of movement –When unilateral, mandible deviates to affected side –Swelling in joint region –When unilateral, infraocclusion on same side
Clinical diagnostic signs	–Pain during active movements –Pain provoked by passive movements –Reproducible pain provocation by manual manipulation (passive compressions, traction, and translations) in *all* directions –Occasionally the lower jaw is held in a protective position	–Pain during active movements –Pain provoked by passive movements –Reproducible pain provocation by manual manipulation (passive compressions, traction, and translations) in *all* directions –Posterior teeth are lifted out of contact –Lower jaw is held in a protective position
Instrumental diagnostic aids	Cannot be diagnosed by occlusal analysis on an articulator or by axiography	–Changes in the intermaxillary relations can be documented by instrumented occlusal analysis –Axiography is not indicated
Imaging diagnostic aids	–Cannot be diagnosed on radiographs –MRI indicated only when a nonreducing disk displacement is suspected: • T1-weighted images in habitual occlusion • T2-weighted images at maximal jaw opening • T1-weighted in corrected coronal plane	–Cannot be diagnosed on radiographs –MRI to confirm joint infusion and to exclude a nonreducing disk displacement: • T1-weighted images in habitual occlusion • T2-weighted images at maximal jaw opening • T1-weighted in corrected coronal plane
Treatment direction	Nonspecific	Varies with the individual, but usually anterior
Impediments in treatment direction	Not relevant for initial pain relief therapy	Not relevant for initial pain relief therapy
Therapy	–Nonspecific pain relief therapy with a stabilization splint at the mandibular position determined by the patient –Anti-inflammatory medication and physical therapy if needed	–Nonspecific pain relief therapy with a stabilization splint at the mandibular position determined by the patient –Anti-inflammatory medication and physical therapy if needed

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Joint Disorders—Ligaments

Insertion tendopathy of the stylo-mandibular ligament (Ernest syndrome)	Capsule hypermobility	Diagnosis
ICD.9.CM 848.1 (nonspecific)	ICD.9.CM 728.4	**ICDA Number**
Painful inflammatory irritation of stylomandibular ligament	Increased mobility of joint due to lax ligaments and surrounding structures resulting from dysfunctional or genetic influences	**Definition**
Anterior	Inferior or anteroinferior	**Loading vector**
—Pain at the angle of the jaw, also occasionally in the joint, ear, and/or radiating to the temporal region —At times, hypersensitivity of the molars as a referred pain	—No pain —Sometimes above average length of excursive movements (jaw opening, protrusion, and mediotrusion)	**Symptoms**
—Painful anterior translation —No pain on passive jaw opening —Pain on palpation	—A "too soft" endfeel in one or more directions during traction and translation —Resilience test is inconclusive	**Clinical diagnostic signs**
Cannot be diagnosed by functional and occlusal analysis on articulator	—Paraocclusal electronic axiography in combination with traction and translations for documentation —Occlusal analysis on articulator and MPI is inconclusive	**Instrumental diagnostic aids**
Cannot be diagnosed by imaging procedures	Cannot be diagnosed by imaging procedures	**Imaging diagnostic aids**
Posterior	None	**Treatment direction**
None	None	**Impediments in treatment direction**
—Friction massage —Injection of local anesthetic without vasoconstrictor —Restoration of a physiological vertical dimension	Not necessary	**Therapy**

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Diagnosis	Condylar luxation	Condylar hypermobility
ICDA Number	ICD.9.CM 830.1	ICD.9.CM 728.5
Definition	Sliding of disk—condyle complex in front of the articular eminence without the possibility of self repositioning	Sliding of disk—condyle complex in front of the articular eminence with the possibility of self repositioning
Loading vector	Anterior initially. Superior after over-rotation	Anterior initially. Superior after over-rotation
Symptoms	—Locked jaw after further opening —Occasional muscle and/or joint pain	—"Springing" of the condyle over zenith of the articular eminence when jaw is opened farther than usual —A distinct click can also occur at terminal jaw opening
Clinical diagnostic signs	—Jaw locked open, patient cannot close —Cannot palpate condyle in fossa	—Inspection: visible over-rotation with acceleration during jaw opening —Palpation of condylar movement —Occasional terminal click during jaw opening —Terminal click can be avoided by slower, manually guided movement
Instrumental diagnostic aids	Cannot be diagnosed by instrumentation	Occlusal analysis on articulator provides no specific diagnostic information Axiography serves primarily for documentation
Imaging diagnostic aids	Imaging procedures provide no additional diagnostic information; serve only for documentation	Provide no additional diagnostic information; serve only for documentation
Treatment direction	Posteroinferior	Posteroinferior
Impediments in treatment direction	—Hypertonicity of elevators —Very rarely, ankylosis in luxated position	—Hypertonicity of elevators and protractors
Therapy	—Reposition using the hand grasp of Hippocrates	—No urgent need for treatment —Instruction in self control to avoid extreme jaw movements

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Muscle Disorders

Myofascial pain	Myositis	Diagnosis
ICD.9.CM 729.1 (nonspecific)	ICD.9.CM 728.81	**ICDA Number**
Localized pain during isometric contraction *and* palpation of a muscle when there is a trigger area in the belly of the muscle, tendon, or fascia	Acutely painful muscle with generalized inflammation and swelling, precipitated by trauma or infection	**Definition**
In the direction of the injured muscle fibers	Nonspecific	**Loading vector**
–A mostly dull pain localized in the muscles –May cause referred pain in a related region	–Acute pain in the whole muscle –Pain increased by movement –Swelling of the affected muscle –Reduced mandibular mobility	**Symptoms**
–Pain during specific isometric contraction and provocation of the same pain by palpation –Pain is reduced by cold spray and muscle stretching ("stretch and spray")	–Swelling can be observed by extraoral inspection –Limited active movement –Passive movement increases pain –Pain with isometric contraction; same pain elicited by palpation	**Clinical diagnostic signs**
Analysis of function and occlusion on instruments is not indicated	Analysis of function and occlusion on instruments is not indicated	**Instrumental diagnostic aids**
Not indicated	Not indicated	**Imaging diagnostic aids**
Opposite to the loading vector	Nonspecific	**Treatment direction**
None	None	**Impediments in treatment direction**
–Relaxation splint –Transverse massage –"Stretch and spray" –Physical therapy –Injection of local anesthetic	–Rest –Physical therapy –Anti-inflammatory medication	**Therapy**

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Diagnosis	Tendinitis / insertiontendopathy	Myalgia
ICDA Number	ICD.9.CM 726.8	ICD.9.CM 729.1 (nonspecific)
Definition	Inflammatory change in the area of a muscle tendon (digastric m.) or the attachment of tendon to bone without evidence of trigger areas	Pain plus feelings of "pulling", fatigue, and bracing in the musculature, but with no pain at rest, no trigger areas or referred pains
Loading vector	In direction of affected muscle fibers and tendons	Specific or nonspecific
Symptoms	—Sometimes mandibular mobility is restricted —Pain in a large insertion area or hypersensitivity of the entire insertion area	—Pain or a "pulling" sensation —Feeling of fatigue and bracing —May be limitation of mandibular movement
Clinical diagnostic signs	—Occasionally, limited active movement —Painful passive movements —Pain during specific isometric contraction —The same pain provoked by palpation	—Isometric contraction usually painless —Provocation and intensification of unpleasant sensations by palpation
Instrumental diagnostic aids	Analysis of function and occlusion on articulator is not indicated	Analysis of function and occlusion on articulator is not indicated
Imaging diagnostic aids	Not indicated	Not indicated
Treatment direction	Opposite to the loading direction	Opposite to the loading direction
Impediments in treatment direction	None	None
Therapy	—Relaxation splint —Transverse massage —"Stretch and spray" —Physical therapy	—As a rule, no cause-oriented treatment is possible —Symptomatic treatment: • Physical therapy • Relaxation exercises (e.g. self training) • Relaxation splint

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Muscle spasm	Functional muscle shortening	Diagnosis
ICD.9.CM 728.85	ICD.9.CM 729.9	**ICDA Number**
Sudden involuntary tonic contraction of a muscle following overextension or overloading, accompanied by pain and reduced mandibular mobility	Painless shortening (fibrosing) of the noncontractile elements of a muscle as a secondary adaptation to hypofunction	**Definition**
In the direction of the contraction	Not applicable. Result of hypofunction	**Loading vector**
—Pain of acute onset, present both at rest and during movement —Continuous muscle contraction —Limited mandibular mobility	—No pain symptoms —Moderate limitation of movement	**Symptoms**
—Pain during active movement —Pain increased by passive movement —Pain during isometric contraction —Same pain is elicited by palpation	—Active jaw opening slightly reduced —A "too soft" endfeel with restriction during passive jaw opening —Shortening of the suprahyoidal structures is indicated by an increase in the sagittal step	**Clinical diagnostic signs**
Increased EMG activity may be measurable at rest	Instrumented functional and occlusal analysis is not indicated	**Instrumental diagnostic aids**
Not indicated	Not indicated	**Imaging diagnostic aids**
Opposite to the loading vector	Opposite to the direction of shortening	**Treatment direction**
None	None	**Impediments in treatment direction**
—Protection from overextension/overloading —Physical therapy	—Physical therapy (dynamic and static muscle extension) —Movement and stretching exercises by the patient —Definitive alteration of the existing hypofunctional postural and movement patterns	**Therapy**

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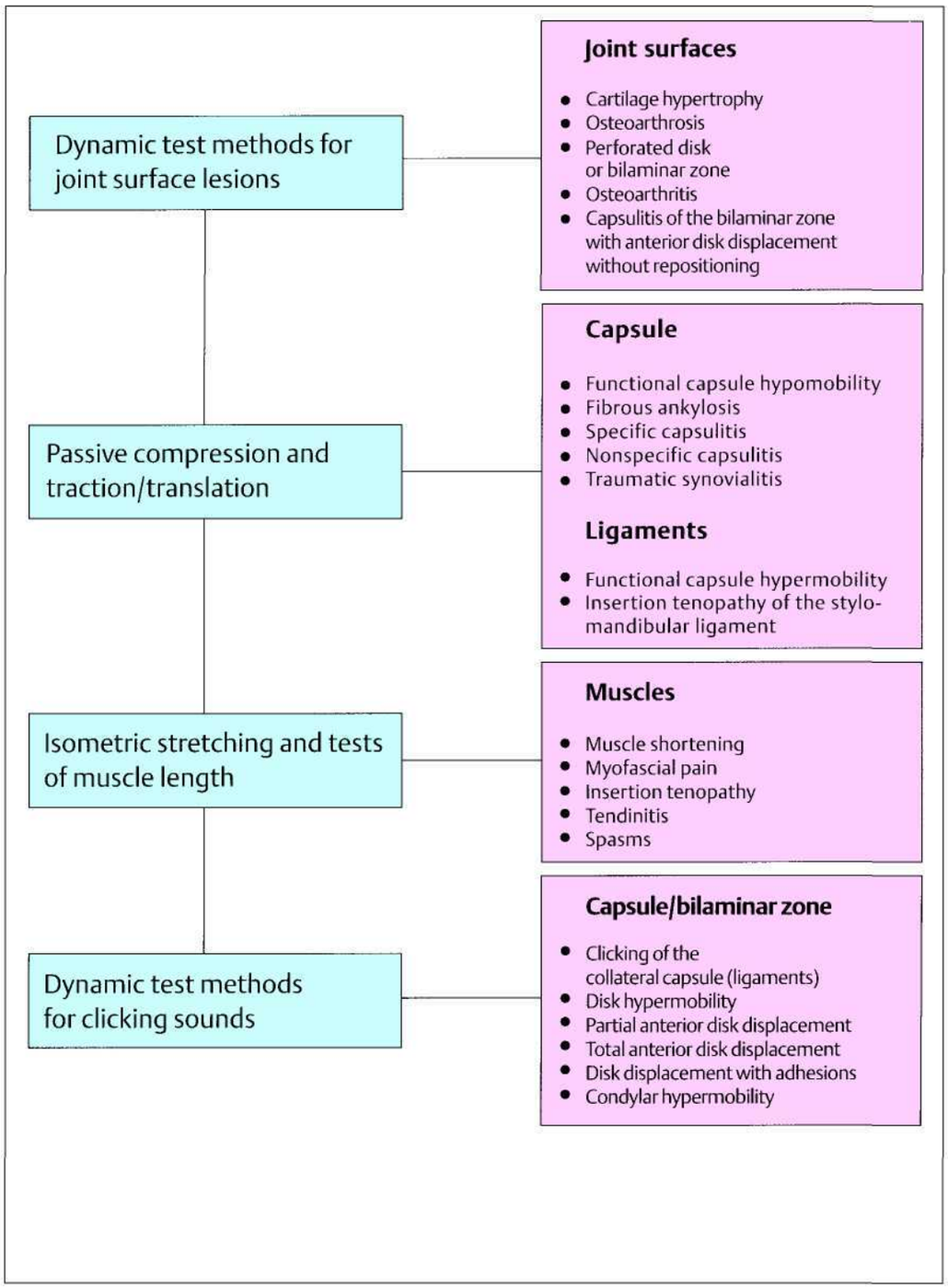
800 Examination techniques and differential diagnosis possibilities



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Principles of Treatment

In this book we shall present only a brief discussion of the basic principles for the treatment of functional disorders. A more detailed description of therapeutic measures is anticipated in a future work.

An individualized functional therapy demands special knowledge in two distinctly separated areas, that of general therapeutic principles and that of specific clinical application. From a study of the literature and the diagrams in Figures 1-3 it is sufficiently apparent that in biological systems symptoms can arise from a multitude of potential etiological factors. The only effective means of treatment, therefore, is the systematic reduction of these harmful influences. It is completely irrelevant by *which* therapeutic measures the symptoms are reduced. By this we mean that the methods of alternative medicine have just as much justification as the procedures learned primarily in school, provided that evidence has been brought forth that they can effectively reduce the harmful influences.

In functional therapy a basic distinction should be made between symptomatic treatment and treatment that is directed toward the causative factors. A *cause-oriented therapy* is possible only if the cause of the symptoms (which may be at a completely different location) is known and can be eliminated by treatment directed specifically toward it. This presupposes a systematic diagnostic procedure with specific identification of the contributing factors. Symptomatic *therapy,* on the other hand, is applied for a generalized reduction of symptoms, frequently without knowing what the etiological factors are. The concept of symptomatic therapy includes many alternative therapeutic measures (dos Santos 1995, Wright and Schiffman 1995), the prescription of medications, alterations of diet (Ciochon et al. 1997, Hinton and Stinson 1997, Loudon 1997), acupuncture (Rosted 1998, Ernst and White 1999), hypnosis (Dubin 1992, Oakley et al. 1994, Crasilneck 1995), cold and heat application (Sturdivant and Fricton 1991, Feine et al. 1997), and psychotherapy (Rudy et al. 1995, Dworkin 1997). The contribution of dentistry is the reduction of occlusal factors with the help of occlusal splints. Only when occlusal vectors are identified in the same direction as the individual loading vectors can splint therapy be called a cause-oriented therapy. In all other cases, an occlusal splint is only a symptomatic treatment aid. Before irreversible alterations of the occlusion are undertaken, it must *always* be established with certainty that a *causal connection* exists between the static or dynamic occlusion and the current loading vector. The role of the physical therapist in the treatment team is to eliminate musculoskeletal impediments (pp. 138 and 304). In this respect a *systematic functional therapy* ultimately comprises three components:

- Diagnosis and relief of overloaded, nonadapted structures (by the dentist).
- Mobilization of unyielding adapted structures (elimination of impediments in the direction of treatment by the physical therapist).
- Permanent reordering of the previous functional pattern (by the patient).

No long-term success can be expected if one or more of these components is missing. The more effectively the structures are unburdened, the more successful the treatment will be. With occlusal splint therapy, for example, there is long-term repositioning of only 36% of displaced disks (Okeson 1988), whereas with the more mechanically efficient Herbst hinge appliance the rate is 87% (Summer and Westesson 1997). Even so, a substantial change in functional patterns (either within the connective tissues or the nerves and muscles) by the patient leads to a significantly better therapeutic result (Turk et al. 1996). Under the *unified concept,* the *interdisciplinary treatment team* is composed ideally of a dentist (to remove local contributing factors), a physical therapist (to remove local impediments), an orthopedist (to remove systemic factors from the musculoskeletal system), and a craniosacral therapist (to remove systemic impediments). Additional adjuvant forms of therapy may also be required in individual cases.

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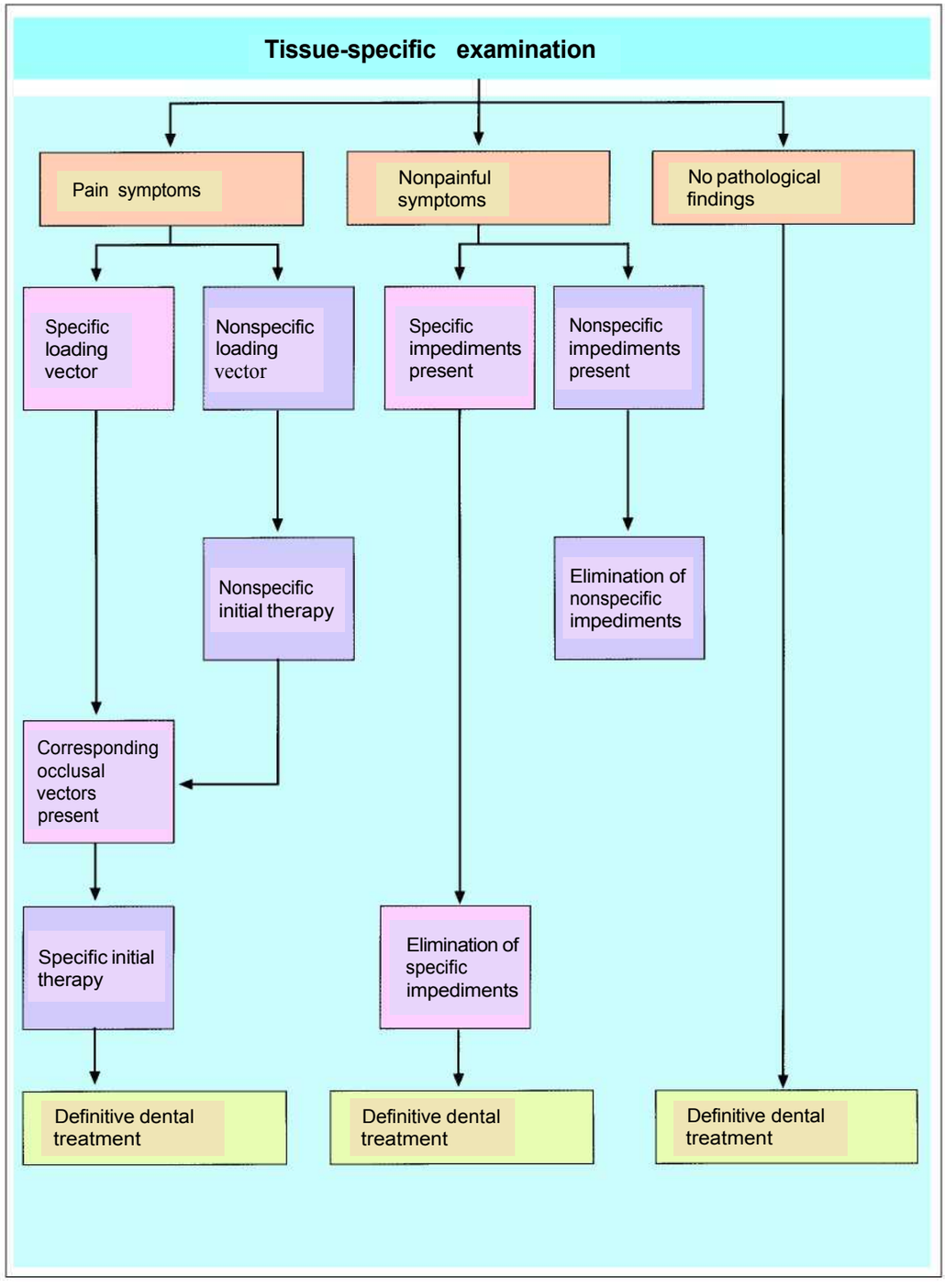
Specific or Nonspecific Treatment?

During a tissue-specific examination using manual functional analysis the clinician may discover painful conditions, painless disorders, or even no pathological conditions at all.

With *painful conditions* there is the question of whether the loading vector is specific (pain can be elicited in only one primary direction) or nonspecific (there is pain from manipulations in multiple directions). If there is a specific loading vector it must be further determined whether or not there is an occlusal vector in the same direction. If this is the case, specific treatment can be provided, first reversibly by means of an occlusal splint and finally by permanently altering the occlusion. If there is a nonspecific loading vector, only nonspecific treatment for relief of pain can be administered (p. 303), at least initially.

The same is true in principle *for painless disorders* (constriction of the capsule and muscles, changes in muscle strength and tonus). If the changes are present in only one main direction, the problem can be addressed with physical therapy. Otherwise, only a nonspecific approach is possible,



801 Specific versus nonspecific therapy
Schematic representation of the diagnostic parameters that lead to the decision as to whether a specific or a nonspecific therapy will be applied.

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Nonspecific Treatment

Nonspecific treatment must always be used when *inflammatory tissue changes* or *nonspecific loading vectors* are present. These cases are usually diagnosed with the aid of the jointplay test (passive compressions, translations, and traction). While patients with positive responses limited to passive compressions can often be given specific treatment, there is no alternative to nonspecific treatment for those with positive responses to both passive compressions and translations, as well as to traction. In this phase, the dental team member may make use of a stabilization splint (with posterior cusp indentations and anterior or canine guidance) and various medications (analgesics, anti-inflammatory drugs, muscle relaxants, sodium hyaluronate, glucocorticoid) (Brazeau et al. 1998). Injections of corticosteroids and hyaluronate can provide pain relief that has been reported as short-term (Kopp et al. 1991, Alstergren et al. 1996, Sandier et al. 1998) and long-term (Wenneberg et al. 1991), but these cause no radiographic changes in the joint, Effects that are frequently observed clinically such as on capsular hypomobility have not yet been systematically investigated,

Common diagnoses with a nonspecific loading vector	Nonspecific treatment measures
Capsulitis	Stabilization splint in the jaw position determined by the patient. Antiinflammatory medication if necessary.
Disk displacement without repositioning	Stabilization splint in the jaw position determined by the patient. Antiinflammatory medication if necessary.
Joint effusion	Stabilization splint in the jaw position determined by the patient. Antiinflammatory medication if necessary.
Acute arthritis	Stabilization splint in the jaw position determined by the patient. Antiinflammatory medication if necessary.
Acute stage of chronic juvenile arthritis	Stabilization splint in the jaw position determined by the patient. Antiinflammatory medication if necessary.
Fracture	Fracture treatment: Antiinflammatory medication if necessary.
Capsule constricted in multiple directions	Nonspecific mobilization of the capsule by means of traction and translations in the anterior, medial and lateral directions.
Disturbance of the innervation of muscle groups with differing directions of contraction	Stabilization of the system over various antagonistic muscle groups

802 Joint disorders with nonspecific loading vector and their initial treatment
A listing of the most frequent clinical diagnoses that can be associated with a nonspecific loading vector.
Regardless of the current diagnosis, nonspecific treatment is instituted for the purpose of converting the nonspecific loading vector (evidenced by numerous nondirectional positive responses during the joint-play test) into a specific one (positive responses in separate limited directions). Only then can a causal relationship between the functional disturbance and the individual occlusion be tested.
The nonspecific pain-relief phase, using a relaxation splint and anti-inflammatory medication usually lasts 3-7 days. If the pain does not significantly decrease during this time, the patient should be referred to a specialist. As soon as the nonspecific treatment for pain has rendered inferior traction and/or anterior translation painless, a physical therapist can be included in further treatment to relieve stresses on the joint.

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Elimination of Musculoskeletal Impediments

Within the concept of interdisciplinary treatment, the primary assignment of the physical therapist is to remove musculoskeletal impediments (= restrictions). From the medical viewpoint, there is no urgent need for this unless restrictions exist in the direction of therapy. There are three separate treatment elements: physical therapy, manipulative therapy, and coordination exercises. The components of *physical therapy* are:

- cold and heat applications
- ultrasound
- laser treatment, and
- transcutaneous electric nerve stimulation (TENS) (Linde et al. 1995, Wright and Schiffman 1995, Conti 1997, Murphy 1997, Pinheiro et al. 1997, Gam et al. 1998, Rosted 1998, Craig et al. 1999, Ernst and White 1999).

Even if long-term success is not realized, physical therapy can help, at least as long as the treatment is continued (Di Fabio 1998). Many methods, however, have proven to have no benefit beyond the placebo effect (Feine and Lund 1997). One exception is treatment with cold (Oosterveld and Rasker 1994), in which ice massages were more effective than cold packs (Zemke et al. 1998).

803 Capsule hypomobility
Left: A structural hypomobility (= constriction) of the joint capsule in the vertical direction can be treated through traction. However, this treatment can be used only if no pain could be elicited in this direction during the diagnostic procedures. The number of treatment sessions varies from one to three per week depending upon the individual case.

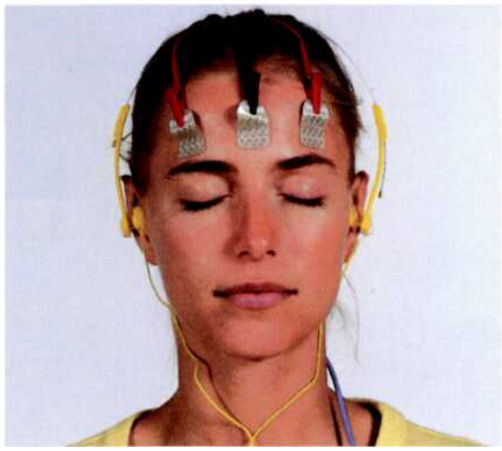
Right: Anterior translation is used to treat capsule hypomobility in the horizontal direction.

804 Shortening of the muscles
Left: Shortening of the noncontractile elements of a muscle (= muscle shortening) is treated by static and dynamic muscle stretching. This is performed by having the patient open the mouth to the first level of muscle tension and then exerting a light isometric force against the clinician's thumb. This causes the contractile muscle cells to stretch the noncontractile elements.

Right: After the mouth has been opened in stages without strain, the procedure is repeated.

805 Muscle hypertonicity
Left: The electrodes of a biofeedback apparatus are placed on the forehead and temples. If the primary involvement is with the masseter or the suprahyoid muscles, the electrodes may also be placed there.

Right: The patient monitors the muscle tonus at any given moment either visually by observing an analog scale of light-emitting diodes, or acoustically by listening to a frequency modulated tone. Biofeedback cannot eliminate endogenous causes, however.



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Manipulative therapy is the essential tool of the physical therapist for treating restrictions in the masticatory system by

- mobilizing the joint capsule
- stretching the muscles, and
- strengthening weak muscles (Friedman and Weisberg 1984, Rocabado 1989, Israel and Syrop 1997).

If constriction of the joint capsule is causing activation of the pain receptors (Type IV, Wyke 1979) within the capsule, mobilization of the capsule may relieve the pain (Kraus 1994). Physical therapy will never provide long-term success unless there is a permanent modification of the patient's *coordination.*

Exercises to improve the patient's general state of physical fitness have a definite beneficial effect on the pain symptoms (Trott and Goss 1978, Minor et al. 1989) because they improve the ability of the system to compensate. Furthermore, specific dynamic exercises can strengthen the muscles, improve function, and reduce pain (Tegelberg and Kopp 1988).

Coordination exercises for the masseter and anterior temporal muscles can also reduce the burden on the joint (Itoh et al. 1997).

806 Reduced muscle strength
Left: Reduced strength in one muscle can upset the mutually antagonistic neuromuscular balance and thereby alter the condylar position. This is especially true of the lateral pterygoid muscle. In the first treatment phase the weak muscle is strengthened by isometric contractions, being performed here for the left muscle.

Right: Dynamic isotonic exercises are performed in the second treatment phase to functionally integrate the strengthened muscle.

807 Disturbance of coordination
Left: There are numerous techniques to improve muscle coordination (Rocabado et al. 1982, Lewit and Simons 1984, Osternig et al. 1987, Cottingham and Maitland 1997). In addition, the patient can perform isotonic exercises independently.

Right: Jaw movement exercises ("jawsercises," Korn 1994) can not only improve coordination, they can also help stabilize the results of the manipulative treatment. Nonspecific exercises should be avoided, however.

808 Homework
Left: "Homework" assignments can serve to support active physical therapy or isolated symptomatic treatment or to stabilize the results of therapy. One very effective technique in this regard is autotraction.

Right: Active movements are usually supplemented by warm applications ("hot packs"). This is in contrast to the treatment for pain, which calls for application of cold.

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Occlusal Splints

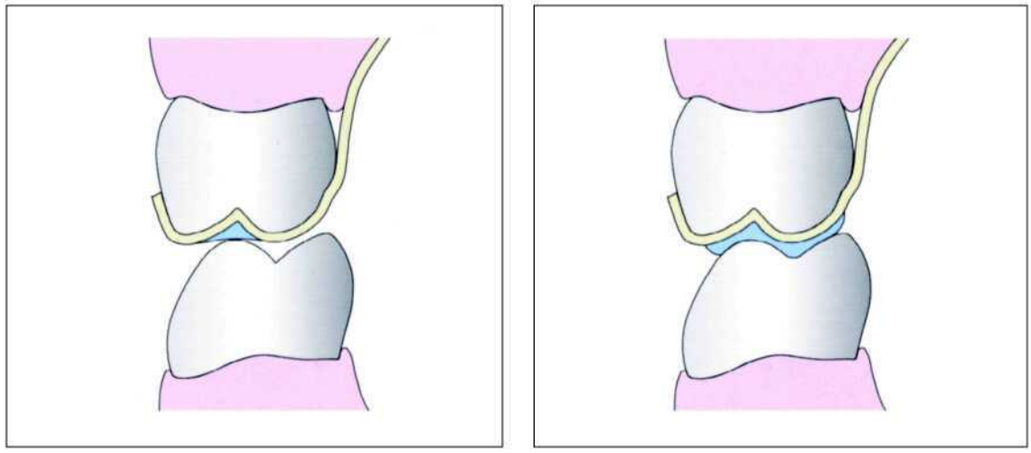
By the term "occlusal splint" or "occlusal device" is meant a removable artificial occlusal surface of plastic or metal that the patient wears temporarily to alter the occlusal contacts and the functional pattern of the mandible. Occlusal splints attempt to create equal contacts of the posterior teeth and to secure the centric or therapeutic mandibular position through maximal intercuspation against the splint.

A primary advantage of the occlusal splint over other types of occlusal treatment is that the occlusion can be altered without making it necessary to then irreversibly modify the patient's natural dentition. Occlusal splints have been appropriately called "spectacles for the teeth" (Stachniss 1984). Early references to the use of occlusal devices for the purpose of relaxing the muscles were made by Goodwillie (1881), Ritter (1884) and Karolyi (1901).

Occlusal splints can be effectively used for the following purposes (Crispin et al. 1978, Clark et al. 1979, Manns et al. 1981, Hamada et al. 1982, Lotzmann 1983, Lundh et al. 1985, Okeson 1987):

809 Principles of splint design in the posterior region
Left In the posterior region the occlusal splint is made flat or with only shallow indentations. This design is preferred for the following: relaxation splints, decompression splints, and in some cases repositioning splints.

Right: Distinct imprints of the opposing cusps help to secure the mandibular position. This is the preferred form for stabilization splints and, in some cases, for repositioning splints.



810 Dynamic occlusion
Left: It is preferred that occlusal splints provide anterior, or at least canine, guidance although they may incorporate other eccentric occlusal schemes. Here canine guidance causes vertical disocclusion of all the otherteeth during lateral jaw movement.

Right: The anterior guiding surfaces of the splint are shaped so that all posterior teeth are out of contact in the protrusive movement also.

- improving neuromuscular coordination
- treatment of myogenic pain
- improving function of the temporomandibular joint
- treatment of pain arising from the joints
- increasing the vertical dimension
- securing a definite mandibular position
- altering the pattern of mandibular movement
- testing the planned occlusal scheme in centric and eccentric positions
- splinting of loose teeth
- distributing the load in bruxism
- clarifying occlusal etiological factors while making a differential diagnosis.

In evaluating the therapeutic effects one must consider that occlusal splints not only affect the occlusion, but also suppress proprioception by splinting the teeth together. Furthermore, parafunctional activities triggered by the initial insertion of the splint can temporarily switch off the actual traumatic parafunctions and give the false impression of a successful occlusal treatment.

Occlusal splints can be placed over either the upper or lower dental arches. Their placement depends upon where areas of lost support must be restored and whether the patient's anterior guidance should be taken over or modified by the appliance. For example, the splint is made for the maxillary

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arch if the inclination of the anterior or canine guidance is uneven or needs to be made steeper.

An occlusal splint is effective only if the patient's neuromuscular system can tolerate its presence and the occlusal changes it brings about. If, on the other hand, an occlusal device causes, supports, or intensifies excessive or persistent parafunctional contacts, the success of the treatment will be endangered. This makes it imperative to observe the following rules when inserting an occlusal splint:

- Occlusal splints must have adequate retention and a precise passive fit.
- Their form should be as thin and "periodontium friendly" as possible without jeopardizing stability and occlusal function.
- In accordance with a cause-oriented therapy, occlusal devices should simulate only those occlusal relationships that can be reproduced essentially unchanged in the final restorations.
- Preliminary occlusal splint therapy that is not diagnosis-specific, that is uncontrolled or is of excessively long duration can bring about pathological and to some extent irreversible changes in the masticatory system, such as caries progression, periodontal disease, tooth movement, and alterations in joint morphology.

811 Occlusal splint for a posteriorly shortened arch
Left: A removable partial denture with inadequate occlusion can be converted into an effective occlusal treatment device by adding acrylic to correct the occlusion. The old plastic teeth are not replaced by new ones until a comfortable mandibular position has been reached.

Right When correctly formed, an occlusal splint can serve as a suitable temporary prosthesis for a posteriorly shortened dental arch ("free-end saddle").

812 Occlusal splints for cases with visible gaps
For greater patient acceptance, occlusal devices should incorporate plastic teeth, at least where teeth are missing in the appearance zone.

From the collection of H Gloerfeld

If the primary cause of the craniomandibular functional disturbance lies in a psychological illness, any form of treatment that is not specifically directed toward the psychological cause can lead to conversion of the psychic illness into physical symptoms (beware: "occlusion neurosis"). The clinician can sometimes satisfy a patient's built-in need for occlusal therapy by merely inserting an occlusal splint. A placebo effect may be achieved even if the occlusion of the splint is inadequate (Greene and Laskin 1972).

The multitude of occlusal devices described in the literature can be classified according to their indications as follows (Lotzmann 1999):

- Occlusal devices that are intended primarily to normalize muscle tone and improve neuromuscular coordination (relaxation splints, vertical dimension splints).
- Occlusal devices that serve primarily to reposition the mandible and decompress joint structures (repositioning splint, decompression splint, vertical dimension splint).
- Occlusal devices to stabilize the jaw relations that were established during the initial course of occlusal therapy, and to determine the most favorable centric and eccentric occlusal scheme for the final restorations (decompression splint, stabilization splint).

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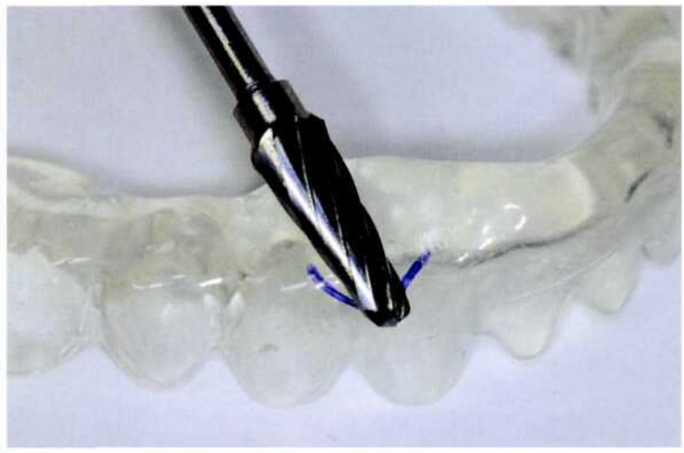
Splint Adjustment for Vertical Disocclusion and Posterior Protection

Adjustment of the splint to alter the dynamic occlusion is carried out primarily in the areas over the canines (for laterotrusion) and the incisors (for protrusion). Depending upon the desired or required occlusal scheme, the dynamic occlusion can be designed to have either anterior/canine guidance, unilateral balance (= group function), or bilateral balance. The most frequently used scheme is, insofar as the position of individual teeth permits, *isolated anterior guidance in protrusive movements* and *isolated canine guidance in lateral movements.* Whereas in protrusive movements only the steepness and length of the guiding surfaces can be changed, there is an additional aspect to the canine guidance where both the amount of *vertical disocclusion* and the so-called posterior protection can be varied. By *posterior protection* is meant that the guiding surfaces in the canine areas are specifically shaped to avoid predominantly posteriorly directed loading. This sagittal protection is indicated whenever a loading direction with a posterior component elicits a painful response (yellow or red) during passive compression.

813 Marking the position of the canine cusps in centric occlusion
The starting point for adjusting the splint for correct vertical disocclusion and horizontal protection is centric occlusion. In this position an outline of the tip of the maxillary canine is projected onto the splint with a felt-tipped pen.

Right: Next the patient executes a lateral movement out of centric occlusion. The ink mark reveals the presence of a posterior component that must be eliminated through treatment.



814 Customizing the angulation of the guiding surface
To treat a posterolateral vector of dynamic occlusion it is desirable to convert the movement into one that is either purely lateral or lateroprotrusive. To that end, the bur is positioned on the lower splint inside the outline of the canine and angled posteriorly and medially to form a groove. During dynamic tooth contact on the right side, this guiding groove causes a reduction of posterior loading on the joint. The degree of angulation depends upon capsule mobility and the length of the suprahyoid structures.

815 Splint adjusted to alter the dynamic occlusion
After completion of the fine adjustments, the sliding contact of the canine on one side against the individualized guiding surface causes disocclusion of all the other teeth (= vertical disocclusion) and a "forced" lateroprotrusion (= sagittal protection) to alter the pattern of movement. If the patient cannot keep the upper canine in the track during light gliding excursions then the angulation of the guiding groove must be reduced.

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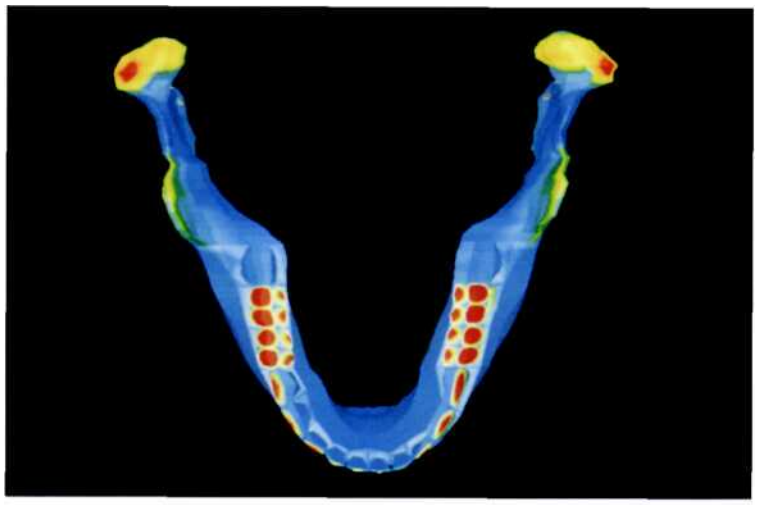
Relationship between Joint Surface Loading and the Occlusal Scheme

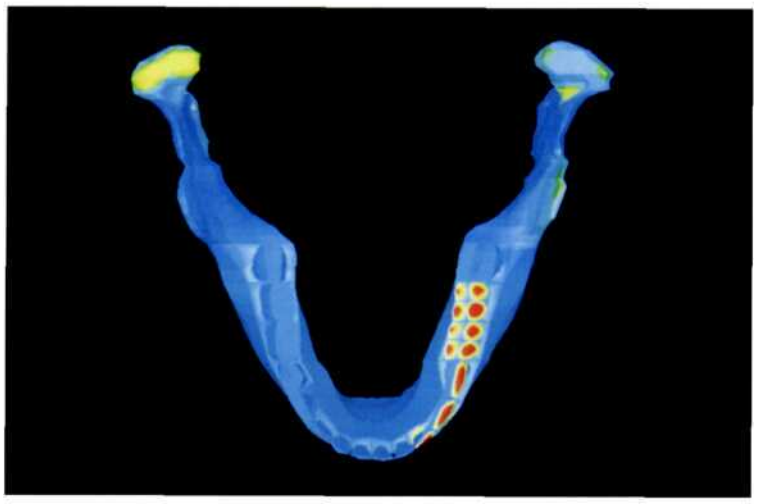
During active mandibular movements the functional joint surfaces of the articular eminence and the condyle are subjected to loads that are usually within physiological parameters (Koolstra and van Eijden 1997). This loading provides a continuous stimulus for the constant renewal of the fibrous cartilage matrix (Carvalho et al. 1993,1995, Roth et al. 1997). Greater loading of the joint surfaces within the physiological range leads to progressive adaptation, but persistent nonphysiological loading leads to regressive adaptation (Jonsson et al. 1999). Joint loading can be influenced by the occlusion. In a healthy or fully adapted masticatory system the anterior/canine protected occlusion is preferred and is the simplest occlusion scheme to establish. In a masticatory system that has already been damaged, however, the preferred occlusal scheme depends essentially upon the direction of the individual loading vector. So, for example, when there are superiorly directed loading vectors on a joint, balancing contacts on the same side are desirable (Fig. 818), but these must be avoided if inferior loading vectors are present together with myofascial pain in the masseter and temporal muscles.



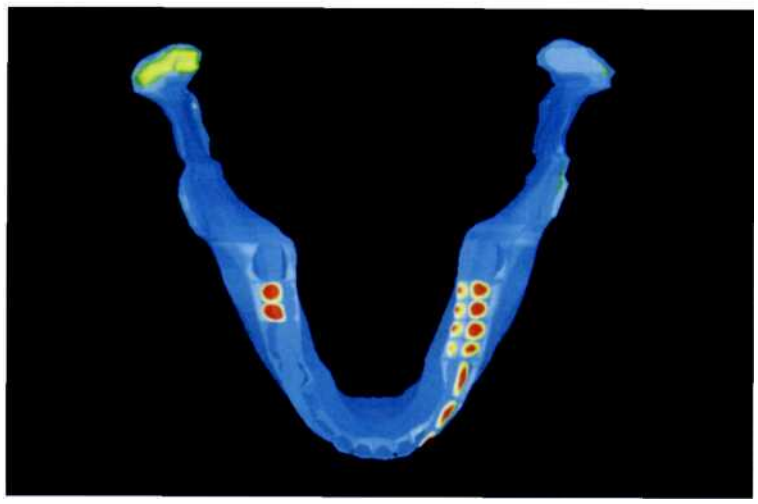
Finite Element Model (FEM)

816 Clenching at maximal occlusion
Distribution of force in the mandible when pressure is applied to a splint that has contact on both sides from canine to second molar. As would be expected, heavy forces (red) are exerted on the teeth. The increased strain at the angles of the jaw and at the condylar poles indicates increased activity of the masseter muscles.

Left: Progression from blue to red on the color scale represents increasing forces.



817 Clenching with unilateral occlusion
The temporomandibular joint is subjected to different forces during an eccentric grinding pattern with unilateral contacts from canine to second molar. On the working side (left condyle) there is virtually no increase in the load. On the non-working side (right condyle) the load on the joint surfaces is much less than during clenching in centric.



818 Clenching with balanced occlusion
A quite different pattern, which is very interesting from a therapeutic standpoint, arises during eccentric bruxing with tooth contacts from canine to second molar on the working side and simultaneous balancing contacts (= mediotrusive contacts) on the contralateral second molars. Electromyographic studies report different responses by the muscles of the balancing side. Apart from the muscular activity, this FEM simulation shows a reduction of the load on the joint surfaces.

Figures 816-818 are from Korioth, T.W.P.: Simulated Physics of the Human Mandible. In McNeill, C.: Science and Practice of Occlusion. Quintessence, Chicago 1997 (pp. 179-186).

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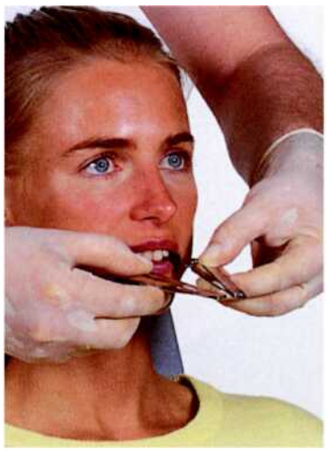
Relaxation Splint

Occlusal devices that are designed primarily to normalize the tonus of the muscles of mastication and at the same time to distribute occlusal forces equally are called relaxation splints. Fabricated to fit either the maxilla or the mandible, the relaxation splint covers all the anterior and posterior teeth in that arch and provides simultaneous uniform contacts in the premolar and molar regions. In a typical case, anterior or canine guidance provides vertical disocclusion of the posterior teeth during excursions. Their *therapeutic action* consists of eliminating centric and eccentric premature contacts, restoring missing posterior support and, when indicated to reduce abrasion, guiding the mandible into a more vertical movement pattern. The change in muscle tone during pretreatment brings with it a lasting change in the jaw relationship and this in turn creates new disruptive occlusal contacts. A comfortable, stable, centric jaw relation with neuromuscular harmony can be achieved only after repeated occlusal adjustments to the relaxation splint. This "settling in" of the lower jaw is referred to as mandibular autorepositioning (Lotzmann 1994).

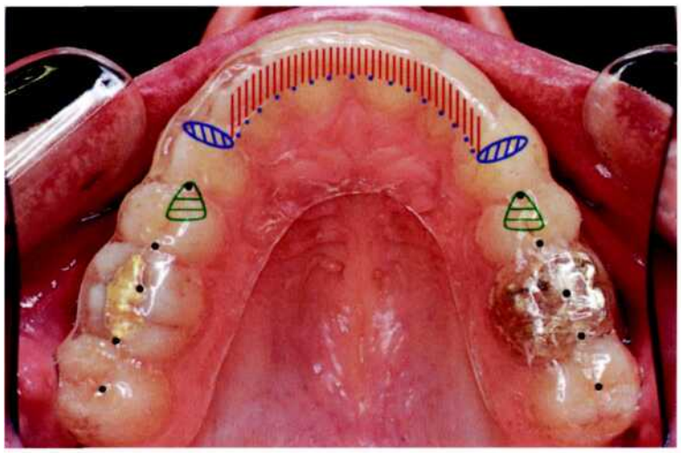
819 Maxillary relaxation splint
The primary goal of treatment with a relaxation splint is to normalize the tonus of the muscles of mastication by equalizing posterior tooth contacts. The occlusal surface of the splint is made flat. Ideally, the posterior occlusal contacts will be against the tips of the functional cusps of the opposing jaw.

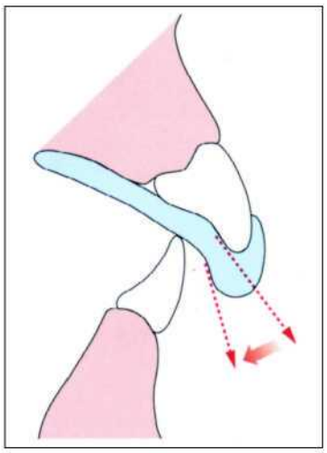
Left: During the preliminary treatment phase the splint must be checked repeatedly for premature contacts and adjusted as necessary.



820 Maxillary relaxation splint
The relaxation splint must fit passively over all the teeth, yet have adequate retention. The U-shaped base may extend farther onto the palate for the sake of stability. In these cases the splint is carefully ground to provide relief over the gingival margins.

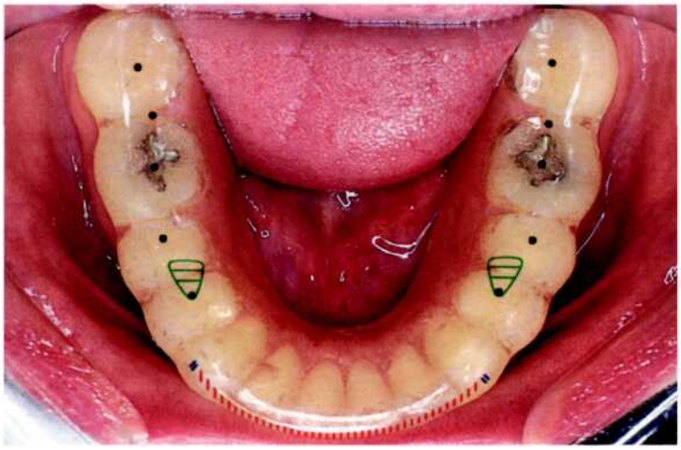
Right: If the length or inclination of the anterior guidance is to be modified, the splint must be fabricated for the maxillary arch.

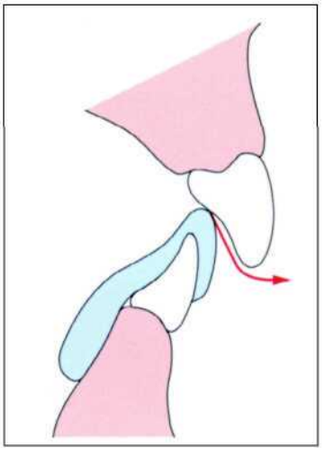




821 Mandibular relaxation splint
A relaxation splint inserted over the mandibular arch is more comfortable to wear than one over the maxillary arch, especially during the first few days of treatment.

Right: If the patient's anterior guidance is to be left intact, the mandibular splint has an additional advantage in that its insertion will not alter the original lingual guiding surfaces of the maxillary incisors and canines.





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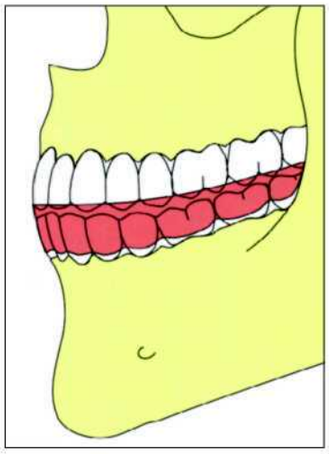
Stabilization Splint

The main purpose of the stabilization splint is to secure the relation of maxilla to mandible that the functional therapeutic steps (physical therapy, temporomandibular joint surgery, orthognathic surgery, etc.) brought about and to test the treatment results for a term of at least 4-6 weeks before the definitive restorations are prepared. This is accomplished by providing maximal occlusion. Stabilization splints differ from relaxation splints in that their occlusal indentations are deeper, although in most cases they also provide anterior or canine guidance. They must be worn day and night.

In the simplest cases, definite intercuspation is achieved through imprints of the cusps into which the opposing teeth can close simultaneously and without interferences. Provisional restorations of metal-reinforced or fiber-reinforced resin are preferred over removable stabilization splints for long-term evaluation of occlusal stability. It is only with provisional restorations that it is possible to test the planned centric occlusal scheme (point, long, or wide centric) at the final vertical dimension and to preview how the patient will accommodate to the final restorations.

822 Lateral mandibular relation with deflective occlusal guidance
The clinical examination suggests that the joint and muscle problems may be caused by the inadequacies of the patient's static and dynamic occlusion.



823 Occlusal splint to stabilize the mandible
Following correction of the occlusion with the help of a relaxation splint and orthognathic surgery, the mandibular stabilization splint serves to secure the newly achieved occlusal position.

Left: Stabilization devices must provide distinct intercuspation.

824 Metal-reinforced, long-term provisional restorations
Provisional restorations with metal reinforcements covered by synthetic resin veneers are inserted to allow long-term evaluation of mandibular stability before the definitive prosthetic reconstruction is begun.

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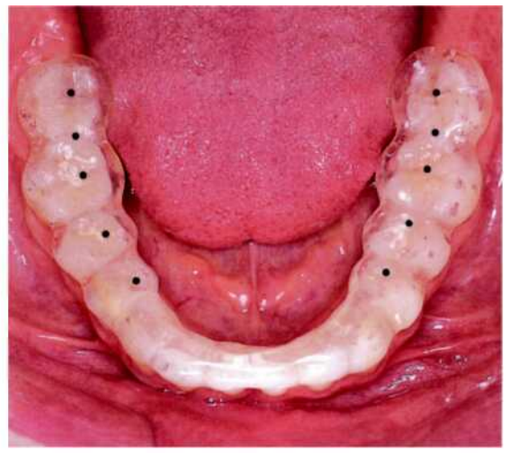
Decompression Splint

The decompression splint is used to treat posteriorly or superiorly compromised temporomandibular joints in which a pronounced constriction of the joint capsule, muscles, and ligaments interferes with the relief of the articular structures that would otherwise be provided by the occlusion. Its design corresponds to that of a relaxation splint with anterior guidance. The actual relief of the compromised joint structures is brought about by appropriate manipulation (inferior traction, translation) to stretch the capsule, muscles, and ligaments. The purpose of the decompression splint is simply to maintain the new inferior or anterior position of the condyles by means of a stable occlusion. Following each physical therapy session (initially 2-3 times each week) maximal occlusion on the splint is carefully tested with articulating tape or shim stock and adjusted as needed by grinding away or adding acrylic resin. For this evaluation of the momentary centric occlusion, the patient is always positioned with head and body upright. Treatment is completed when the joint capsule can be mobilized no farther.

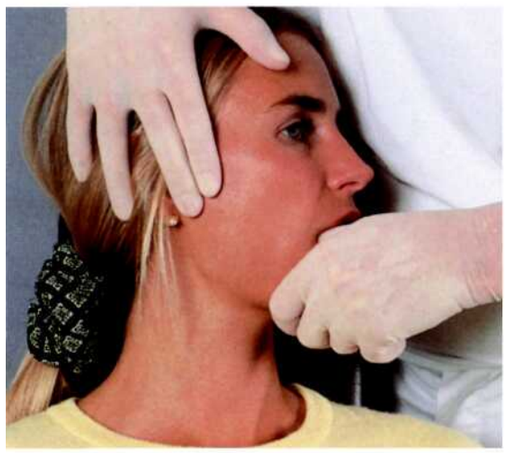
825 Insertion of the decompression splint
Left: The decompression splint is inserted in the chosen dental arch. It should be made to fit the centric jaw relation existing at the moment ("momentary centric").

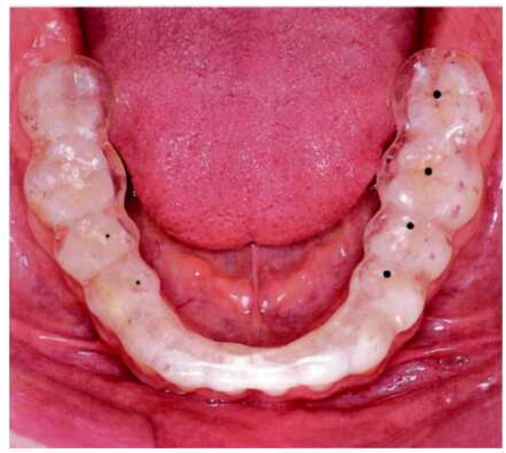
Right: The occlusal surface of the decompression splint has only slight indentations. Posterior contacts are exclusively against the tips of the functional cusps of the opposing teeth.



826 Capsule mobilization
Left: Special manipulation techniques such as the inferior traction illustrated here can be used to loosen up the fibrosed joint capsule and thereby create the conditions necessary for relieving stresses on the compromised joint structures.

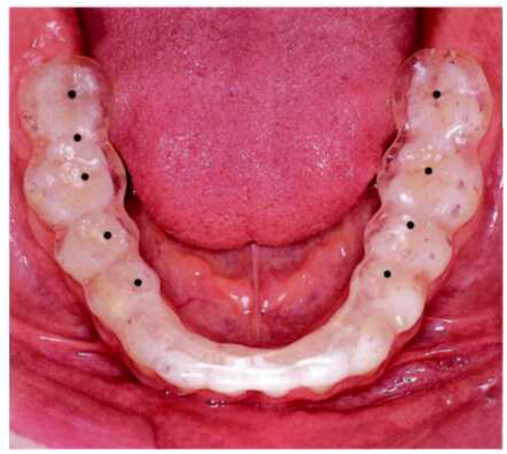
Right: Because of the inferior repositioning of the condyle that goes along with successful mobilization of the temporomandibular joint, there is no longer posterior tooth contact on that side. Occlusal evaluation is always performed at the "momentary centric."





827 Splint adjustment following mobilization
Left: Preferably, decompression splints should be made with anterior, or at least, canine guidance.

Right. The appliance should provide maximal intercuspation, and the occlusion should be equilibrated immediately after physical therapy by adding or removing material to maintain the unloading of the joint structures achieved through manipulation (cf. Fig. 826).



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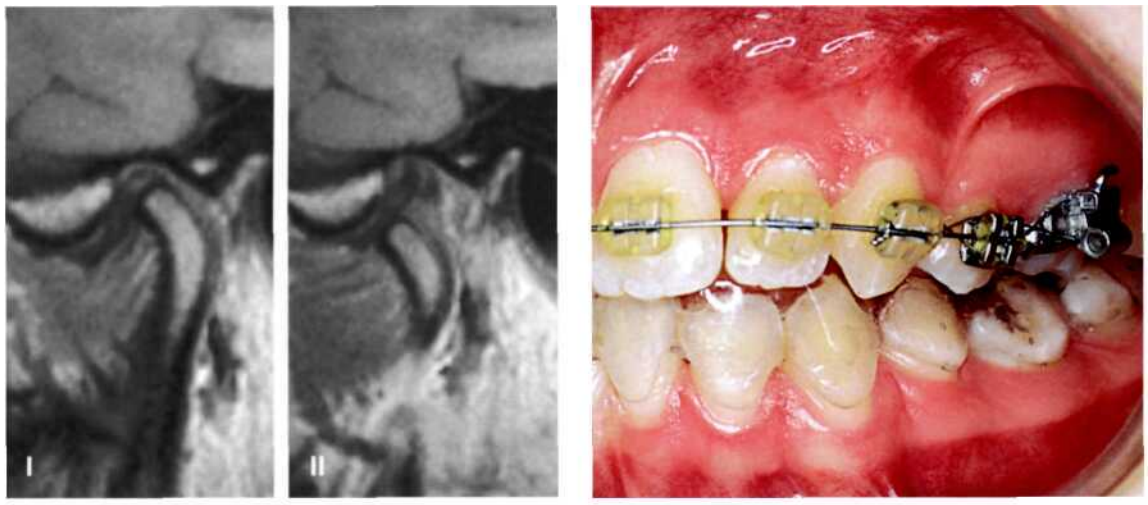
Repositioning Splint

A repositioning splint is an occlusal device inserted to reposition a disk that is partially or totally displaced anteriorly when the teeth are in maximal intercuspation. The maximal intercuspation of the repositioning splint is built up in the *therapeutic mandibular position.* This corresponds to the most posterosuperior position of the mandible at which there is still a correct positional relationship between disk and condyle. The therapeutic mandibular position always lies anterior to the patient's maximal intercuspation position. The therapeutic position cannot be determined unless the displaced disk spontaneously snaps back over the condyle with an audible or palpable click during excursive mandibular movements. Bimanual manipulation and paraocclusal axiography serve to register the "click-free" mandibular position. The actual condyle-disk relationship can best be checked with MRI. There is no indication for a repositioning splint if the disk has been anteriorly displaced for a long time, the bilaminar zone is well adapted, and the patient is experiencing no distress.



828 Repositioning splint in the treatment position of the mandible
Left: MRI at maximal intercuspation (I) and treatment splint position (II) at the start of preliminary treatment. Continued treatment will attempt to further centralize the stable condyle-disk complex through repeated registrations.

Right: Repositioning splints must be worn day and night to protect the joint from relapse of the condyle onto the bilaminar zone.

829 Occlusal design
Left: The bilateral symmetrical retrusion facets in the premolar regions ensure the disocclusion of the remaining posterior teeth as the mandible is guided by the tooth surfaces posteriorly out of the therapeutic intercuspation of the splint.

Right: The treatment position of the mandible is secured by the maximal intercuspation of the splint, which is distinct and free of interferences. Most of the occlusal load falls in the posterior region. An effort should always be made to create anterior guidance or at least canine guidance.

830 Activator-like repositioning appliance for night-time use
Left: The lingual shield permits unhindered opening and closing of the mouth while preventing the mandible from falling back into the original pathological position.

Right: This modified repositioning splint is worn only in the upper arch and provides equal contact with the anterior and posterior teeth. The lingual shield makes anterior and retrusive guiding surfaces superfluous.

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Verticalization Splint

The basic design of a verticalization splint is the same as that for a relaxation splint with equilibrated posterior occlusion. It is made to create a calculated increase in a presumably inadequate vertical dimension and must be worn day and night. The purpose of a verticalization splint is to test the planned vertical dimension increase for neuromuscular acceptance before any permanent changes in the occlusion are made.

Whether the proposed "bite opening" can be accomplished in one step or over multiple phases depends upon the interocclusal distance at the assumed rest position of the mandible. Where extensive abrasion has occurred, an interocclusal distance of 3-4 mm indicates that muscular adaptation to a reduced vertical dimension has occurred. In order not to exceed the capacity of the nerves and muscles to adapt, it is advisable to increase the vertical dimension to the desired value in two or three smaller steps, complementing the treatment with static and dynamic muscle stretching. Absence of discomfort and a new mandibular rest position signify neuromuscular adaptation to the altered vertical dimension.

831 Reduced vertical dimension in an edentulous patient
The ability of a patient to adapt to a new dental prosthesis declines with age. For this reason one should exercise restraint in making permanent changes in old dentures even though they are deficient. As a rule, it is better to make alterations and modifications on duplicate prostheses *(from the collection of M. Steinberg).*

Right: Pronounced loss of vertical dimension with inadequate lip support.

832 Verticalization splint with complete dentures
An alternative to constructing new dentures is placement of a removable verticalization splint. This permits progressive modification of the jaw relations, without irreversible changes, in the old complete dentures to which the patient is accustomed.

Right: The same patient as shown in Figure 831 following correction of the vertical dimension. The new vertical dimension was determined clinically and tested for patient acceptance by means of a verticalization splint.

833 Verticalization as a preprosthetic step for a patient with few teeth
Here, because there was a large interocclusal distance of 14 mm, it was possible to increase the vertical dimension initially by 12 mm without impinging upon the mandibular rest position.

Right: The casts mounted at the definitive and verified vertical dimension document the extent of the "bite raising."

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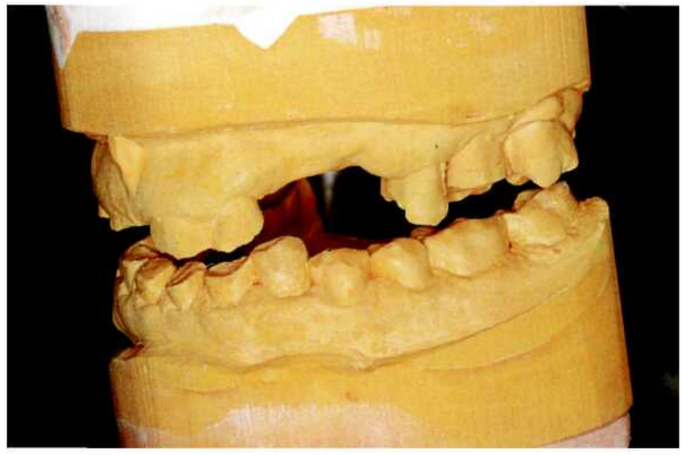
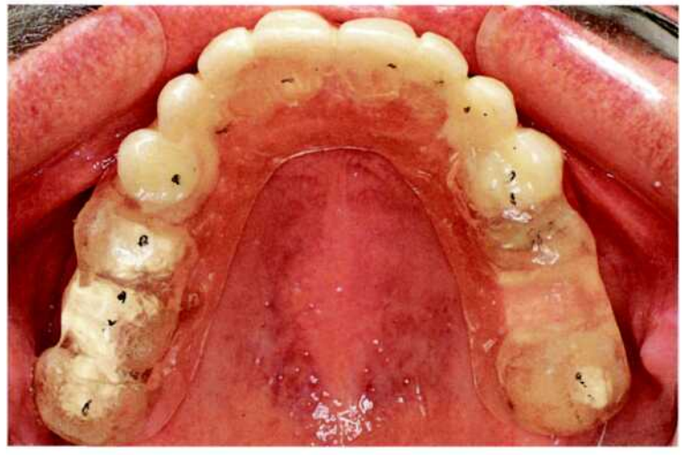
834 Reduced vertical dimension with muscular adaptation
Excessive attrition from tooth-guided parafunction has caused a reduction of the vertical dimension of occlusion. In spite of the considerable loss of tooth structure, neuromuscular adaptation has maintained the interocclusal distance (rest space) at only approximately 2 mm. For this reason, the vertical dimension must be increased to the desired amount in more than one step.



835 Intermaxillary relation following verticalization
The increased vertical dimension shown here was accomplished in two successive steps of 3 mm and 4 mm to avoid exceeding the patient's ability to adapt.



836 Occlusal view of the verticalization splint
The posterior occlusion at the newly established vertical dimension provides equal support in all areas.

837 Verticalization splint over prepared tooth facets
To make it easier for the patient to wear the splint during the 3-month preliminary treatment period, anterior veneers were incorporated into it.

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Definitive Modification of the Dynamic Occlusion

Dynamic occlusion is defined as tooth contacts during mandibular movements. With movement, the location, direction, and number of tooth contacts change. One dynamic occlusal scheme cannot apply to all patients because of the complexity of the mandibular movements (Yaffe and Ehrlich 1987), although as a rule an attempt is made to create incisor and canine guidance. It is possible to reproduce in a limited way an individual's dynamic occlusion on an articulator (Tamaki et al. 1997). Group function is the most frequently occurring form of dynamic occlusion. Approximately 50% of patients exhibit balancing contacts for the first 1.5 mm of a lateral excursion and 33% at excursions of 3 mm (Ingervall et al. 1991). No direct relationship can be demonstrated between balancing contacts and specific dysfunctions (Hochman et al. 1995) even though balancing contacts do result in altered condylar pathways on an axiogram (Sarinnaphakorn et al. 1997). When there are superior loading vectors and in the presence of bruxism (p. 309), balancing contacts are even desirable from a therapeutic standpoint because they reduce the load on the joint surfaces. This is supported by other studies (Minagi et al. 1990). The dynamic occlusion may be

838 Modification of the dynamic occlusion on a maxillary canine
Left: Initial situation in a 17-year-old patient with abraded maxillary and mandibular canines. Clinically there were complaints of nonspecific muscle tension. No joint-related functional disturbances were present.

Right: Building up the maxillary canine with a veneer ensured disocclusion of all the other teeth during lateral movement of the mandible to the right.

From the collection of P Roth

839 Abrasion of the mandibular canine
Left: Abrasion of the mandibular canine has progressively worsened during the 5 years following placement of the veneer on the maxillary canine. This has caused the previously established lateral disocclusion to be lost once again. There is now group function on this side and mediotrusive interferences on the nonworking side, accompanied by muscle discomfort.
Right: This photograph with the jaws slightly opened reveals the advanced wear facet on the lower canine.
From the collection of P Roth

840 Mandibular restoration
Left: The mandibular canine has been built up with a veneer.

Right: Right lateral excursion 1 year after placement of the mandibular restoration. The vertical disocclusion is adequate, although optimal posterior protection (p. 308) could not be created. Modification of the protrusive dynamic occlusion seldom has any positive effect on joint problems. However, it can often ameliorate feelings of fatigue and tension in the muscles of mastication.

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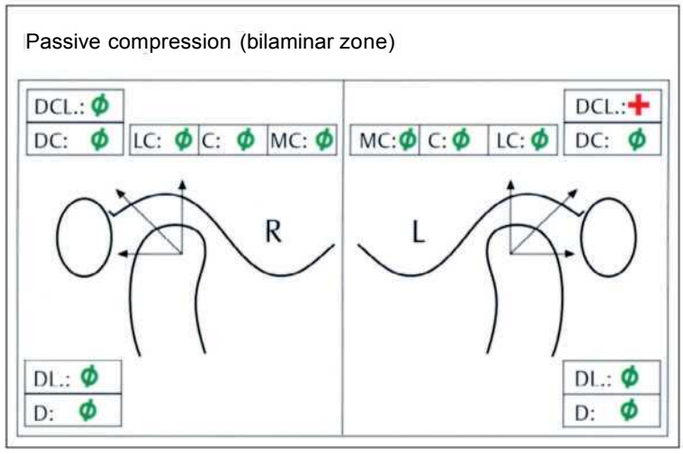
changed by means of restorations for etiological, symptomatic, or prophylactic considerations. An etiology-oriented procedure is indicated if during testing of the dynamic occlusion (p. 130) a discrepancy in the direction of the loading vector is diagnosed between the condylar position at habitual occlusion and at eccentric mandibular position. When considering any permanent modification of the dynamic occlusion, the difference between canine guidance and group function plays only a subordinate role. It is much more important to provide guidance on maxillary mesial-facing inclines for mandibular distal-facing inclines (Fig. 840 right). Hyperactivity in the muscles of mastication can be reduced by canine guidance. In patients with complete dentitions, the steeper the canine guidance, the more noticeable the initial reduction in EMG readings (Soneda 1989). Similar results can be found in complete denture wearers with different occlusal designs (Miralles et al. 1989, Grunert et al. 1994). Muscle activity during parafunction can be reduced in healthy patients (Belser and Hannam 1985). In bruxism patients, however, there is no difference in EMG activity between canine guidance and molar guidance (Rugh et al. 1989). Clinically, patients seem to find a moderate canine guidance to be the most comfortable, but there is no reliable correlation with EMG activity readings.



841 Passive compressions
A section of the examination record of a 26-year-old woman who came for consultation regarding pains in the left temporomandibular joint. The pains she described could be reproduced by passive compressions in a posterosuperolateral direction. The tissue-specific diagnosis, therefore, was "decompensated capsulitis with posterosuperolateral (PSL) loading vector."

842 Habitual occlusion, left side
Analysis of the static occlusion revealed a minimal anterior-posterior discrepancy between centric occlusion/condylar position and habitual occlusion/condylar position. Because of this, the static occlusion is providing relief for the patient's loading vector. The same occlusal vector could have been identified by analysis with a mandibular position indicator (MPI) or by a paraocclusal electronic axiograph corrected for projection errors.

843 Premature contact in dynamic laterotrusion
Evaluation of the dynamic occlusion revealed no posterosuperolateral dynamic occlusal vector. During left lateral movements, however, interferences occurred in the molar region. The arrangement of the wear facets provided clear evidence of bruxing in the posterosuperolateral direction. If the bruxism ceases with a relaxation splint and if the periodontium has not already been damaged, one should allow these interferences to remain for protection of the temporomandibular joint.

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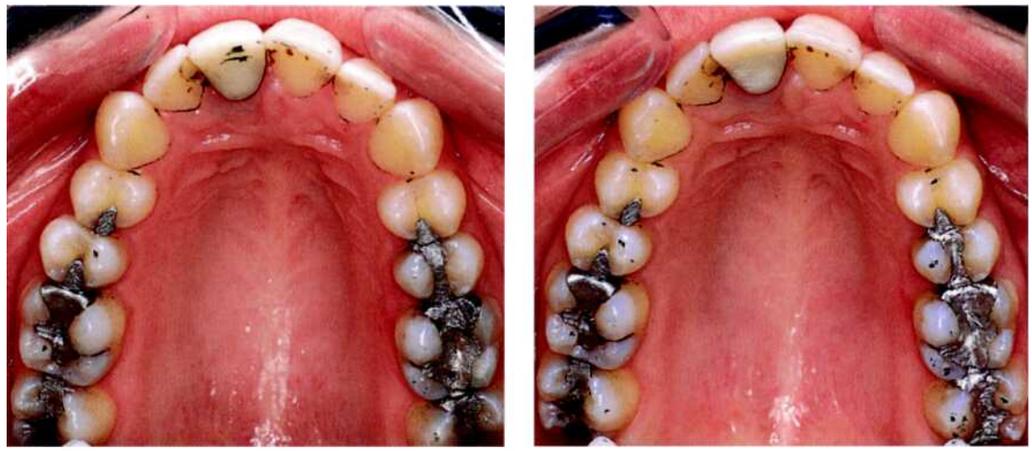
Definitive Alteration of the Static Occlusion

A successful outcome of the preliminary therapy is characterized by freedom from pain, normal muscle tone, improved muscle coordination, and stability of the centric position or the adapted neuromuscularly determined mandibular position. The question now is *which if any* corrective or restorative measures will be necessary to permanently stabilize the patient's static and dynamic occlusion. This can only be answered with the help of an occlusal analysis on the articulator including diagnostic equilibration, waxup, and, if needed, a diagnostic setup. Regarding the mounting of casts for occlusal analysis and permanent restorations, it is especially important that the mandibular position arrived at during the preliminary treatment be transferred to the articulator with great care.

Definitive occlusal corrections are accomplished mainly by a combination of
- selective grinding
- prosthodontic restorations, and
- orthodontic and surgical corrections.

844 Selective grinding of the occlusion
The premature centric contact on the metal-ceramic crown is causing occlusal trauma to the right central incisor and posterior deflection of the mandible.

Right: The forced occlusal guidance has been relieved through selective grinding of the iatrogenic premature contact on the lingual surface of the crowned central incisor. This has eliminated the patient's problem (capsulitis with specific loading vector).



845 Orthodontic and prosthetic measures to stabilize the occlusion
Left: In this patient there was a posteriorly shortened dental arch ("free-end" situation) distal to the maxillary right second premolar. The second premolar has been distalized by an orthodontic appliance and then held in its new position by a retainer that would be considered rather unconventional today.

Right: After a brief time the resin-bonded retainer was replaced by a long-term, metal-reinforced provisional bridge.

846 Orthodontic and oral surgical measures
Left: Presenting condition of a 24-year-old woman with an anterior open bite *(above)*. There is tooth contact only in the first and second molar regions. Through 6 months of preliminary orthodontic treatment *(below)* the dental arches were reshaped and straightened.

Right: Maximal intercuspation 2 years after surgical and orthodontic adaptation of the mandible. The molars have been treated with onlays.

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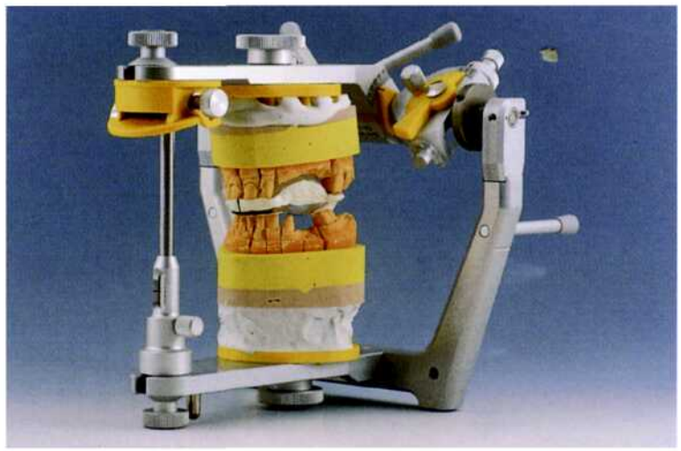
If it has been necessary to perform orthodontic corrections or orthongnathic surgery, then a relaxation splint should be inserted again for 3-4 weeks before the final fine occlusal adjustment is accomplished by selective grinding or placement of restorations. Regardless of the decision made as to how to carry out the occlusal treatment and which occlusal scheme is to be utilized, the occlusal form should always be fine tuned in the patient's mouth. The *goals* of the definitive occlusal treatment are (Lotzmann 1998):

- the achievement or maintenance of freedom from symptoms
- occlusal comfort while chewing
- favorable distribution of forces
- absence of occlusal trigger factors that might initiate, support, or worsen excessive parafunction
- long-term stability of the occlusion with preservation of the capacity for normal occlusal abrasion.

Close interdisciplinary cooperation is most important for successful reconstruction of the occlusion. Here the role of a competent laboratory technician must not be underestimated. An exacting prosthodontic restoration can be created only after extensive professional consultation and exchange of information.

847 Reduced vertical dimension due to hypodontia
This 28-year-old patient has an unstable maximal intercuspation with an abnormally short vertical dimension. Furthermore there are retained primary teeth and congenitally missing permanent teeth. The molars have already been orthodontically uprighted.

Left: Profile view of the patient with teeth in habitual intercuspation prior to treatment. In profile it is obvious that the reduction in height of the lower face is inconsistent with the patient's age.



848 Casts mounted at the corrected vertical dimension
The sectioned casts have been mounted using a centric jaw registration made on the verticalization splint. The thin layer of Temp-Bond painted onto the labial and buccal surfaces of the maxillary splint defines the future position of the maxillary anterior teeth as determined previously on the patient. An instrumented occlusal analysis on the articulator allows the dentist to determine whether it is realistic to attempt to restore the teeth at this mandibular treatment position.

849 Long-term provisional restorations of Targis/Vectris
The long-term provisional restorations shown here were made of Targis/Vectris material and cemented with zinc phosphate cement. They serve to stabilize the maximal intercuspation position at the increased vertical dimension. The patient remains free of discomfort 2 years after insertion.

Left: The profile photograph shows the marked improvement in the patient's external appearance made by the increased vertical dimension.

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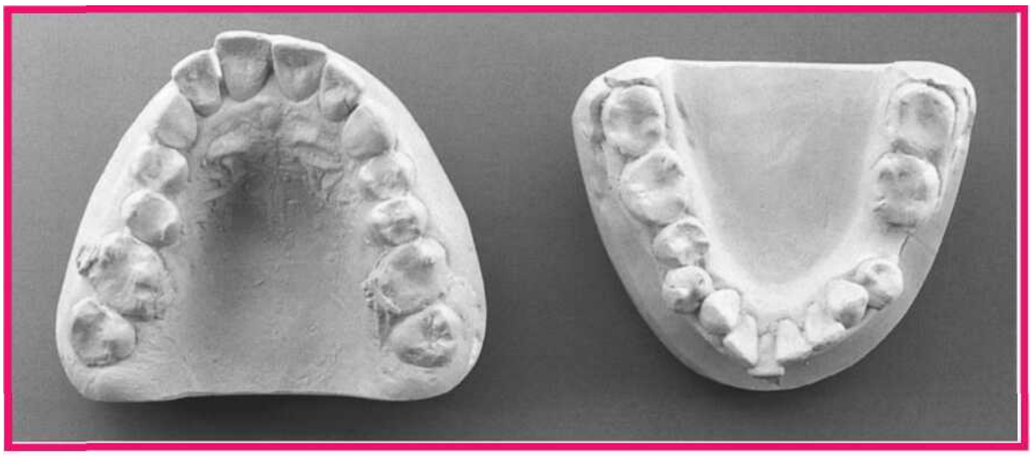
850 Example of interdisciplinary dental treatment (initial casts)

This 46-year-old woman sought consultation for pain in both temporomandibular joints (capsulitis with specific loading vector on both sides) and clicking sounds on the left side (total disk displacement with disk adhesion). There was a distocclusion the width of a premolar on both sides. The horizontal overlap (overjet) was 7 mm and the vertical overlap (overbite) 8 mm. There is extensive crowding of the mandibular anteriors and protrusion of the maxillary anteriors.



851 Tooth realignment phase and autorepositioning of the mandible

In the first phase of treatment the teeth are straightened orthodontically. A maxillary occlusal appliance adapted over the molars and retained by elastic loops is used to provide disocclusion and to stabilize the mandible. This arrangement allows free movement of the six anterior and two premolar teeth and free adaptation of the mandible with unloading of the joints. During this phase the patient's pain symptoms completely disappeared.

852 Stabilization of the treatment position and closing of the posterior open bite

After the new mandibular position was stabilized, composite resin was bonded to the lingual surfaces of the maxillary incisors to hold the treatment position of the mandible. The posterior open bite was then slowly closed by elastic bands. The vertical extent of the composite buildups is determined by the original findings, and with deep overbites this usually results in an overcorrected position.

853 Refinement of the occlusion

As soon as the temporary posterior open bite is closed so that the posterior teeth can hold shim stock, the composite buildups can be removed from the lingual concavities of the central incisors. After completion of this phase it is only necessary to perform fine adjustments of the occlusion. The final result of orthodontic treatment must be retained for 1 year before new prosthetic restorations are placed. In this case separate positioners made of Copyplast (from Scheu) were used as retainers.

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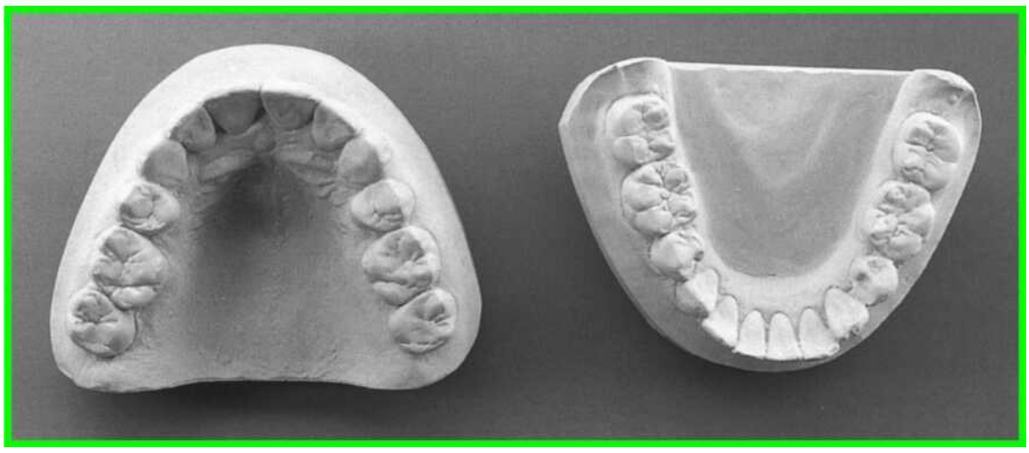
854 Occlusal splint therapy after orthodontic treatment
Completion of the orthodontic treatment was followed by 4 weeks of preliminary treatment with a maxillary relaxation splint with guidance on the incisors and canines to refine the centric jaw relation. To maintain the desired mandibular position the splint was successively readapted to the teeth as they were prepared for crowns and finally served as the centric registration record for mounting the master casts

855 Modeling of the functional chewing surfaces in wax
The posterior teeth were formed taking into consideration the space within which the function of the mandibularteeth against the maxillary teeth primarily occurs.

From the collection of D Schulz

856 Maximal occlusion
The final restorations are fabricated according to the following principles: Simultaneous axially directed contact of all posterior teeth together with lighter contact of the anterior teeth in centric. Incisor and canine guidance for vertical disocclusion and premolar guidance for posterior protection during excursions.



857 Casts of completed case
Comparison of the final casts with the initial casts shown in Figure 850 illustrates the improvements in the alignment of the anterior teeth and the shape of the dental arches. Following extraction of the lower right second premolar, the mandibular posterior spaces were closed insofar as possible by moving the molars forward. The lower antenior teeth had to be tipped forward to reduce the sagittal step and compensate for the skeletal angle class II occlusion. This made a functionally acceptable anterior guidance possible.

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Examination Methods and Their Therapeutic Relevance

In conclusion, it is appropriate to point out once again the relevance of the various examination methods to the treatment outcome. Whereas in the chapter "Nomenclature and Classification" therapeutic principles were described based upon tissue-specific diagnoses, the listing presented here describes which diagnostic steps call for which therapeutic measures by the dentist, physical therapist, or oral surgeon. It should be mentioned once more that only the fundamental principles of treatment are presented in this volume. Unified treatment approaches, especially with the inclusion of orthopedists, physical therapists, and craniosacral therapists have been increasingly utilized by the authors in recent years. These therapies are coming more and more into the foreground, but consolidated data from controlled studies are still required to prove their efficacy. While treatment of patients with chronic facial pain implies an interdisciplinary team approach, local therapeutic measures by dentists or physical therapists can be successful in preventing earlier problems from becoming chronic.

858 Schematic representation of the examination techniques, possible differential diagnoses and treatments

Each separate examination technique can lead only to certain limited diagnoses. If a presumptive clinical diagnosis has already been established, it is often very advantageous to know which diagnostic technique will lead to the shortest path to a successful conclusion. The exact definitions and diagnostic parameters of the various tissue-specific diagnoses are described thoroughly in the chapter "Nomenclature and Classification." In the columns under "Dental therapy" and "Physiotherapy" the general therapeutic possibilities of the two disciplines are listed. Oral surgical procedures are included under the heading "Dental therapy."

Examination steps	Diagnosis groups	Dental therapy	Physical therapy
Dental examination	– Caries – Periodontal – Diseases of the mouth and jaws	Operative, restorative, or surgical treatment	None
Radiographic	– Fractures – Tumors – Syndromes	Conservative or surgical treatment	Perioperative mobilization
Active movements	Non conclusive differential diagnostic information	None	None
Endfeel with passive mouth opening	– Capsule constriction – Muscle shortening – Nonreducing disk displacement – Hyperplasia of the coronoid process – Disturbance of innervation	Decompression treatment or disk fixation if needed. Diskectomy or ostectomy of the coronoid process	Removal of musculoskeletal impediments
Dynamic compression and dynamic translation with compression	– Osteoarthrpsis – Osteoarthritis – Capsulitis with npnrepositioning disk displacement – Disk perforation	Elimination of the occlusal part of the overall loading vector	Removal of musculoskeletal impediments
Passive compression	Capsulitis with distinct loading vector	Elimination of occlusal part of the overall loading vector	Removal of musculoskeletal impediments
Traction and translations	Capsulitis with distinct loading vector	Elimination of occlusal part of the overall loading vector	Removal of musculoskeletal impediments
Endfeel with traction and translation	– Capsule hypomobility – Capsule hypermobility	For capsule hypomobility: decompression therapy	Removal of musculoskeletal impediments
Isometric exertion	– Myofascial pain – Decreased muscle strength	For myofascial pain: "stretch and spray" or local anesthetic injection	– Transverse rubbing – "Stretch and spray" – Isometric and isotonic exercises – Removal of musculoskeletal impediments
Length of suprahyoid structures	Horizontal or vertical shortening of suprahyoid structures	None	– Cervical spine extension – Origin-insertion stretching – Hyoid mobilization
Dynamic compression and dynamic translations	– Differentiation of the stages of disk displacement – Clicking of the lateral ligament – Condyle hypermobility	Elimination of occlusal part of the overall loading vector	Removal of musculoskeletal impediments

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Figs. 831

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Figs. 659

G. Seubert, Durmersheim
Figs. 675

D. Schulz, Bensheim
Figs. 673 R, 674 R, 676-683

Figures 816-818 were taken from **Korioth, T. W. P.: Simulated Physics of the Human Mandible. In McNeill, C: Science and Practice of Occlusion. Quintessence, Chicago 1997 (pp. 179—186).**

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